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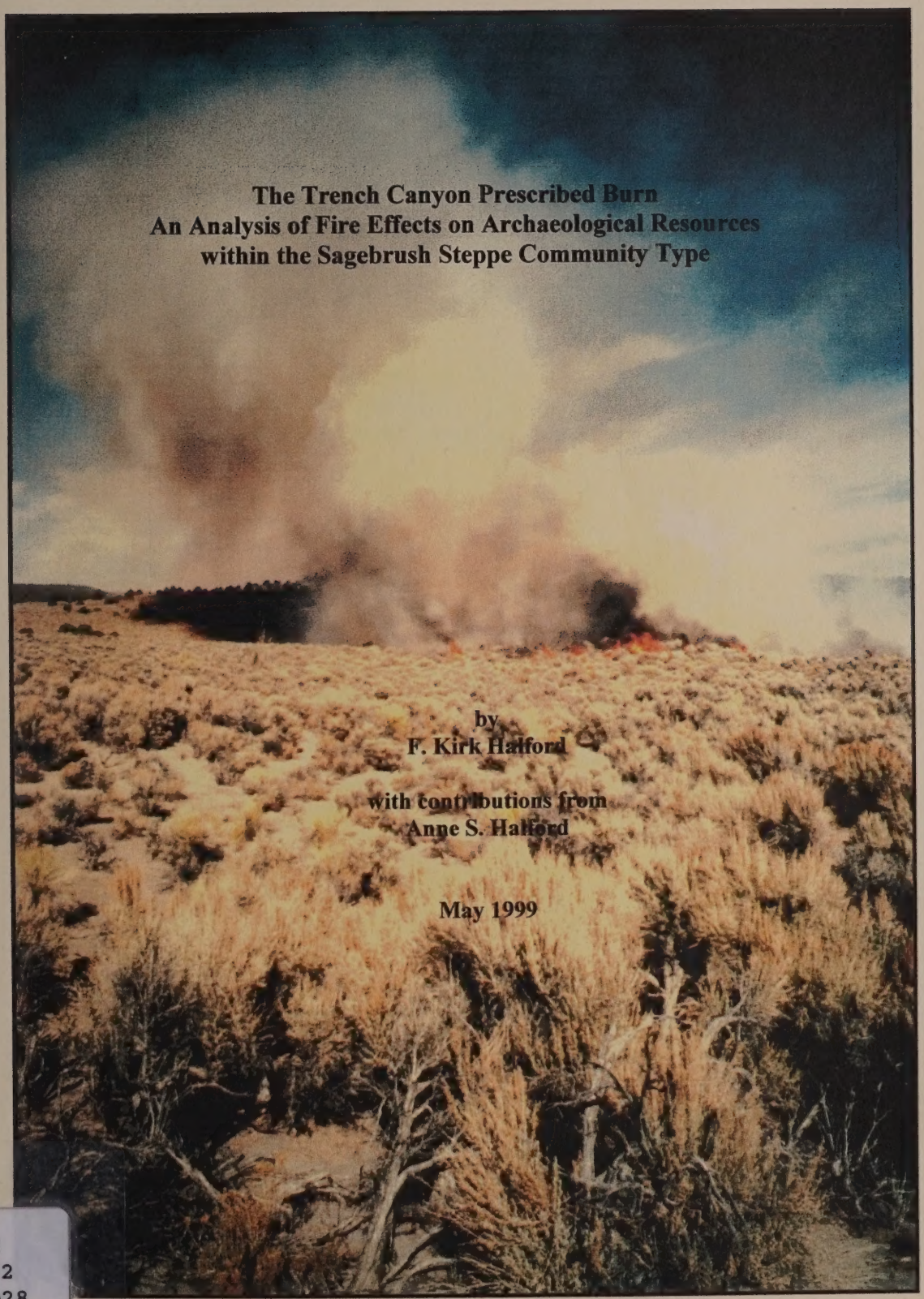

The Trench Canyon Prescribed Burn
An Analysis of Fire Effects on Archaeological Resources within the Sagebrush Steppe Community Type

by
F. Kirk Halford

with contributions from
Anne S. Halford

May 1999

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Acknowledgements

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Abstract

Prescribed fire is becoming a common tool on Public Lands to manage fire behavior, fuel loading and vegetation community associations. The effects of this management practice on archaeological resources is of concern. This paper will focus on the effects of a prescribed burn on the hydration birefringent rim of obsidian artifacts. In particular, this analysis addresses the differential effects of fire within three quantified fuel zones within late seral Great Basin sage (*Artemisia tridentata* ssp. *tridentata*) and upland sagebrush steppe community types.

Introduction

Wildfires and prescribed burns in forested habitats have been shown to cause significant impacts to archaeological resources (Anderson and Origer 1997; Deal and McLemore 1997; Jackson 1997; Lentz et al. 1996; Trembour 1979, 1990). Impact levels are highly variable and are mainly related to fuel types, densities, fire intensity and duration. As prescribed fires are increasingly used as a tool in ecosystem management, continuing research is needed to quantify the potential affects of such management fires on cultural resources.

While some investigations have been concluded in forested habitats (Connor et al. 1989; Deal 1997; Duncan 1990; Eininger 1990; Lentz et al. 1996) very little research has been reported from analyses conducted in the sagebrush steppe ecotype. One exception is Green et al. (1997) who reported on prescribed fire analyses within the upland sagebrush steppe community type, dominated by mountain big sage (*Artemisia tridentata* ssp. *vaseyana*). Research of fire effects on cultural resources has been focused on post fire assessments with little pre-fire control data. Controlled analyses need to be conducted to objectively evaluate and quantify fire impacts on cultural resources.

This paper provides an assessment of the effects of prescribed burning, under controlled conditions, on cultural resources in the Trench Canyon area, located within Mono Basin, Mono County, California (Figure 1). The burn area is on public lands administered by the Bureau of Land Management, Bishop Field Office. Five archaeological sites were recorded during an archaeological investigation of the project area in 1997 (Figure 2). These sites consist primarily of obsidian flaked stone assemblages and, to a lesser degree, ground stone material. It has been shown that freshly exposed surfaces on obsidian nodules or artifacts, such as those caused during the manufacture of tools, begin to absorb water, which diffuses into the interior resulting in the formation of a microscopically visible birefringent front or hydration band (Skinner and Thatcher 1998). Through time, the front penetrates deeper into the artifact, providing an indicator of the age of the exposed surface. In the Inyo-Mono region, obsidian hydration has become an extremely important analytical tool for assessing a site's chronological attributes and can provide important information regarding questions as far ranging as hunter-gatherer mobility, exchange, technology, subsistence and changing land-use patterns. For cultural resource management purposes this dating method can be used as an indices to evaluate a site's significance and potential eligibility for the National Register of Historic Places (NHPA). It has been shown that moderate to high intensity fires can negatively affect the measurable hydration rind on an artifact causing a vague to unreadable diffusion front (Origer 1996).

This analysis is focused on one prescribed fire event within a sagebrush steppe habitat and addresses the effects of this event on obsidian flaked stone artifacts. The emphasis is on the differential effects of fire, within the variable fuel types in the project area, to the hydration diffusion front on obsidian artifacts. To assess the impacts, a control test of six 1 m^2 test plots was conducted. Test plots were placed within three quantified fuels types, i.e. heavy, moderate and light (Table 1). A sample of 180 obsidian artifacts that had been previously subjected to hydration analyses were selected. Each plot was set up with a sample of 30 artifacts, 10 each at the 0 cm, 5 cm and 10 cm levels.

A fire prescription was developed to reduce the high density of Great Basin sagebrush (*Artemisia tridentata* ssp. *tridentata*) in the project area. This vegetative component is suppressing the regenerative potential of the native perennial grass understory, primarily comprised of Great Basin wild rye (*Leymus cinereus*). To aid in prescription development, weather conditions were collected for one year utilizing a Remote Area Weather Station (RAWS). These data were employed to develop the final parameters (e.g., temperature, wind speed, fuel moisture, etc.) under which the prescribed burn should be conducted (Table 3). The vegetation goal of this project is to restore a sagebrush-grass mosaic into a site dominated by dense, monotypic stands of sagebrush and subsequently increase the compositional and structural diversity to the site.

Great Basin wild rye (*Leymus cinereus)* is generally considered to be well adapted to fire (Mason 1981; Sheeter 1968; Stubbendiek et al. 1986). Crowns have coarse stems which tend to insulate perennating buds located at or just below the ground surface. As a result, the majority of plants survive fire to become components of the postburn plant community. Surviving plants sprout from basal buds, and in some ecotypes, from rhizomes (Wright et al. 1965). Some post-fire seedling establishment is also expected to occur. To increase the positive affects of postfire regeneration of Great Basin wild rye the fire was timed to occur during periods of plant dormancy. Fall is documented to be the most optimal time to achieve rapid recovery of this species (Vallentine 1961; Wright et al. 1982; Zschaechner 1985).

Questions directing the assessment of the effects of fire on obsidian artifacts, under the prescription developed for Trench Canyon, include:

1) What are the impacts of prescribed burning within the sagebrush steppe habitat on prehistoric archaeological resources, with a focus on obsidian artifacts?

2) What are the differential effects between low, moderate and high density fuel zones?

3) What are the differential effects of fire between surface and subsurface artifacts.

4) Do fires within the sagebrush steppe ecotype significantly impact the data potential of prehistoric archaeological resources rendering determination of NHPA eligibility difficult?

Based on previous research, it is hypothesized that prescribed fire within the Trench Canyon sagebrush steppe habitat will not adversely affect the data potential and significance of

prehistoric flaked stone assemblages located on the fringes of the heavy fuel zone. It is predicted that no subsurface artifacts will be affected in the low and moderate fuel zones (as described below), while a loss of up to 70% of the hydration rinds is expected to occur in the 0-5 cm level in the heavy fuels. This analysis will test these hypotheses with a goal to facilitate archaeological survey strategies and management prescriptions for controlled burns in the similar vegetation types in the future.

Previous Fire Studies

Previous fire effect studies have been conducted under wildfire, controlled, and laboratory conditions (see Deal 1997; Jackson 1997 for overviews). The conclusion is that the two most important variables affecting obsidian hydration is fire intensity and duration. In general, hot fires (> 260° C) will have an adverse effect on the hydration band, but low intensity fires which occur for long duration's can also have negative effects. Smoldering roots, stumps or duff have been shown to effect artifacts, and temperature maximums may occur well after the fire has burned through an area leaving hot, smoldering ground litter (Deal 1997:7; Deal and McLemore 1997). The threshold for the loss or diffusion of the birefringent front begins at about 500° F (260° C) and is seriously effected at 800° F (427° C) (Deal 1997; Green et al. 1997). The main effect on obsidian hydration is that the birefringent front expands, causing a diffuse and unreadable hydration band (Rob Jackson, personal communication 1998; Deal 1997; Origer 1996). Burned specimens often show macroscopic surface alterations such as spalling, sooting, weathering and may take on a waxy chatoyance (Jackson 1997; Origer 1996).

The most adverse effects to obsidian hydration occur to artifacts on the surface where temperatures as high as 13001° F (7051° C) have been recorded in the chaparral and subsurface temperatures can reach excesses of 2001° F (931° C) (Hull n.d.:21-22), though temperatures generally are significantly lower under prescribed fire conditions. Fuel loading, vegetation type and topography are some of the key variables affecting a fires intensity. Surface fuels, such as duff and pine needles, will carry fire along the ground causing increased soil temperatures and result in increased subsurface temperatures which can adversely effect hydration readings. But various studies show that artifacts below 5 cm show only moderate effects from fire (Anderson and Origer 1997; Deal 1997). Artifacts below 10 cm show no measurable effects (Anderson and Origer 1997; Reynolds 1998).

The Research Area

The Trench Canyon study area is located along the California/Nevada border (Figures 1 and 2) in the northeast corner of Mono Basin, Mono County, California. Mono Basin is a structural depression formed at the base of the eastern piedmont of the Sierra Nevada Range. During the terminal Pleistocene (ca. ~35,000-12,000 B.P.) the hydrographically closed basin was inundated by pluvial Lake Russell (present day Mono Lake) which covered a ~650 km^2 area and reached elevations as much as 200 meters above the current lake level of 1944 meters (Grayson 1993; Stine 1990). Remnant lake shores flank the project area. Today, Mono Lake covers an

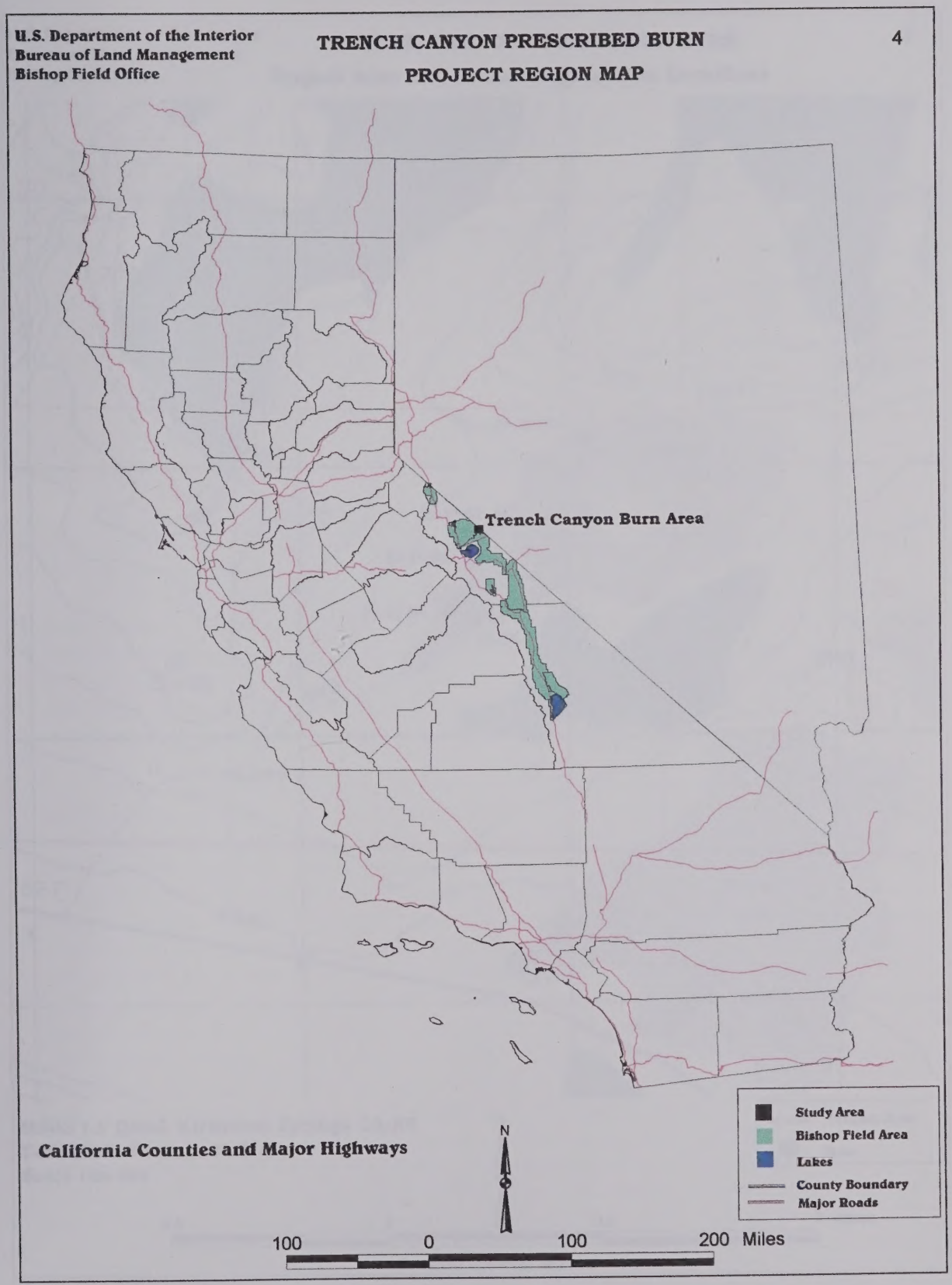

U.S. Department of the Interior
Bureau of Land Management
Bishop Field Office
TRENCH CANYON PRESCRIBED BURN
PROJECT REGION MAP
4
Trench Canyon Burn Area
California Counties and Major Highways
N
Study Area
Bishop Field Area
Lakes
County Boundary
Major Roads
100
0
100
200 Miles

Figure 1.

U.S. Department of the Interior
Bureau of Land Management
Bishop Field Office
TRENCH CANYON PRESCRIBED BURN
Project Area and Archaeological Site Locations
30
29
28
33
7038T
7082T
6889T
6926
7000
4WD
97-29-S3
97-29-S4
97-29-S5
97-29-S6
97-29-S1
Sand Dunes
5-145
6897T
6844AT
6889
Sand Dunes
USGS 7.5' Quad: Kirkwood Springs, CA-NV
T4N, R28E, Sections 32 & 33
Scale 1:20 000
N
Project Area
Sites
0.5
0
0.5
1 Miles
Contour Interval 40 Feet

Figure 2.

area of roughly 180 km^2. Trench Canyon is a small, remnant embayment of ancient Lake Russell, characterized by well developed sand dunes formed of aeolian lake deposits. The project area is within a level to sloping basin (0-15% slope) with a south/southwest aspect at an elevation of approximately 2074 m. The soils consist of Quaternary lake and aeolian deposits, characterized by clayey soils in the basin, fringed by the dune and gravely lake shore deposits. It is on the dune complexes, on the perimeter of the basin, that the archaeological sites occur (Figure 2). Average precipitation ranges from 20-30 cm and the dominant vegetation includes Great Basin sagebrush (*Artemisia tridentata* ssp. *tridentata*), Great Basin wild rye (*Leymus cinereus)*, needle and thread grass (*Hespirostipa comota*) and annual and perennial buckwheat (*Eriogonum)* species. Great Basin sagebrush, which dominates the basin, reaches heights up to two meters, with canopies spreading one to two meters in diameter, and bases up to 20 cm in diameter.

Trench Canyon Archaeological Evaluations

A Class III archaeological inventory was conducted in the project area in 1997. Five prehistoric sites were recorded, all located in the dune areas on the fringe of the basin (Figure 2). The sites range in size from 1,508 m^2 (97-29-S3) to 5,655 m^2 (97-29-S6). The sites consist primarily of obsidian flaked stone assemblages. The flaked and tool stone profiles indicate that mid and late stage biface thinning were the main reduction activities at the sites. Ground stone material occurs in small proportions (i.e., ≤ 3 items) and are ephemeral in nature, with grinding surfaces showing limited use wear. Active aeolian sand deposits suggest that subsurface remains may occur, but during test plot set up (mainly in and near site 97-29-S5, Figures 5 and 6) no subsurface deposits were encountered.

Forty five obsidian toolstone and flaked stone specimens were submitted to the Northwest Research Obsidian Studies Laboratory (Skinner and Thatcher 1998) from the project area. Of these, 25 specimens were subjected to X-ray fluorescence (XRF) and all 45 to hydration analyses. The results of these studies are summarized in Appendix A with a full report in Appendix B. Two samples were submitted from site 97-29-S1, thirty from 97-29-S3, three from 97-29-S4, and ten from 97-29-S5. The XRF analyses identified the representation of five sources in the sample, dominated by Mt. Hicks which is located in the closest proximity to the project area to the northeast (Mt. Hicks n=20 (80%), Bodie Hills n=2 (8%), Casa Diablo (Lookout Mtn.) n=2 (8%), Silverpeak n=1 (4%)). The hydration analyses provide a range of readings from 3.2 to 12.2 μm (mean= 4.8 μm, SD=2.1 μm). The majority (67%) of the hydration readings fall in the 3.0 to 3.9 μm range. These data, along with a few diagnostic points (n=3, 1 Rosegate [4.4 and 3.5 μm], 1 Elko form? [6.1 μm], 1 dart stemmed form? [7.7 μm]), indicate that the project area was visited by hunter-gatherer groups from the Paleo-Indian to the Haiwee periods (ca.12,000 to 650 B.P.), with the most prevalent period of use during the Newberry/Haiwee interface (ca. ~1,350 B.P.). The high frequency of sites in the project area and the temporal dimensions indicated by the hydration analyses, suggest that the Trench Canyon area provided an important resource patch for hunter-gatherers moving through the area.

Methods

Fuel Types

The study area can be classified, in a broad sense, as a brush-dominated fuel group, fitting into "Fire Behavior Fuel Model 6" (Anderson 1982:9), with 100 (1-3" dia.) and 1,000 (> 3" dia.) hour fuels. One hour (< ¼") and 10 hour (1/4-1") fuels are also prevalent. This group was further separated into three sub-types. To determine the three quantifiable fuel sub-types that occur within the study area, a total of six 25 m transects were established within vegetation zones that exhibited heavy (dense), moderate and low fuel cover. Vegetation and duff (litter) cover was then measured using the Line Intercept Method (Canfield 1941), which measures cover intercepts along the course of a line (tape). Foliage and basal cover are derived using this method. Fuel categories were then determined based on the following criteria: Heavy fuel types were those areas that contained 60-100% shrub cover (*Artemisia tridentata* ssp. *tridentata* and *Chrysothamnus naueseosus).* Moderate fuel types contained 20-60% shrub cover and low fuel types contained less than 20% shrub cover (Table 1 and Figures 3 and 4).

Transect	Plant Species	Fuel Type	% Cover
1	*Artemisia tridentata* ssp. *tridentata*	Heavy	**69**
2	*Artemisia tridentata* ssp. *tridentata*		**65**
	Acnatherum hymenoides		0.02
	Leymus cinereus	Heavy	0.004
3	*Artemisia tridentata* ssp. *tridentata*		**15**
	Chrysothamnus nauseosus		**9**
	Eriogonum davidsonii		4
	Achnatherum hymenoides		3
	Lupinus purshii		1
	Leymus cinereus	Moderate	0.2
4	*Chrysothamnus nauseosus*		**17**
	Achnatherum hymenoides		7
	Artemisia tridentata ssp. *tridentata*		**4**
	Eriogonum davidsonii		0.2
	Leymus cinereus	Moderate	0.02
5	*Chrysothamnus nauseosus*		**9**
	Achnatherum hymenoides		5
	Hespirostipa comota		4
	Eriogonum davidsonii		0.04
	Leymus cinereus	Light	0.08
6	*Hespirostipa comota*		8
	Chrysothamnus nauseosus		**6**
	Artemisia tridentata ssp. *tridentata*		**5**
	Achnatherum hymenoides		1
	Leymus cinereus	Light	1

Table 1. Dominant species within the heavy, moderate, and light fuel types. Shrub species percent cover values are in bold-face type.

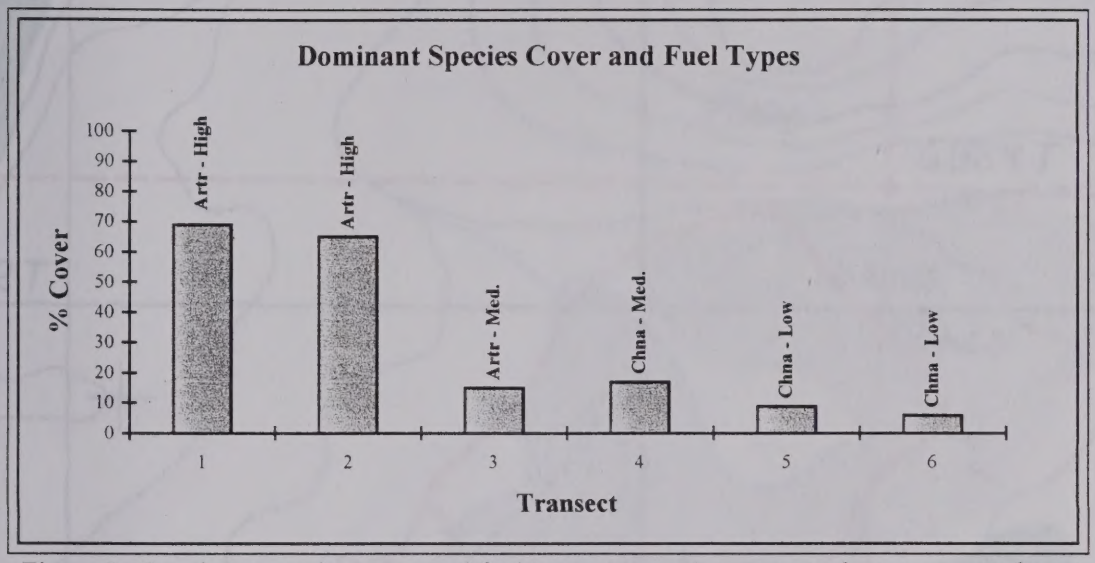


Figure 3. Dominant species cover and fuel type. Artr = *Artemisia tridentata* ssp. *tridentata*, Chna = *Chrysothamnus nauseosus*

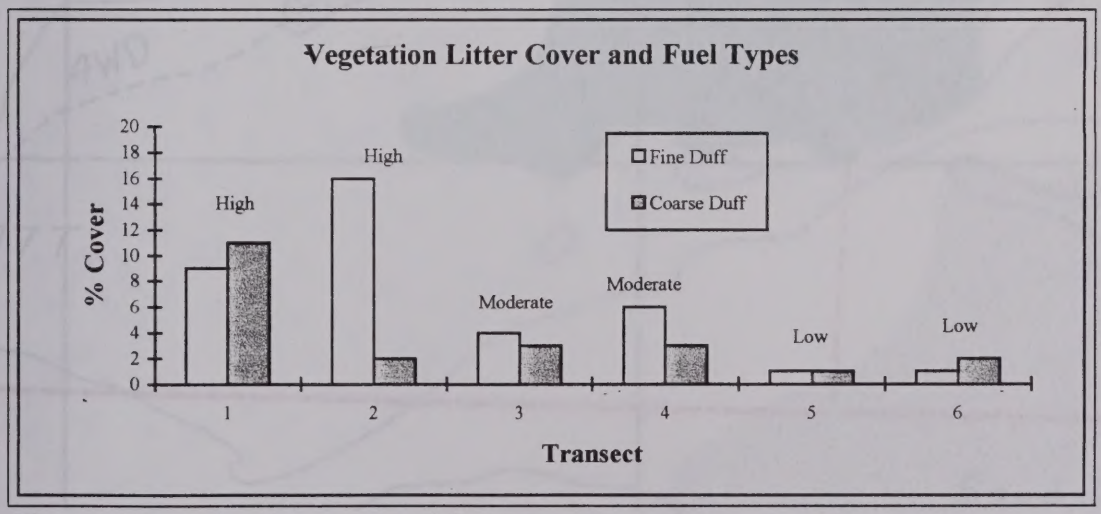


Figure 4. Vegetation litter cover and fuel types.

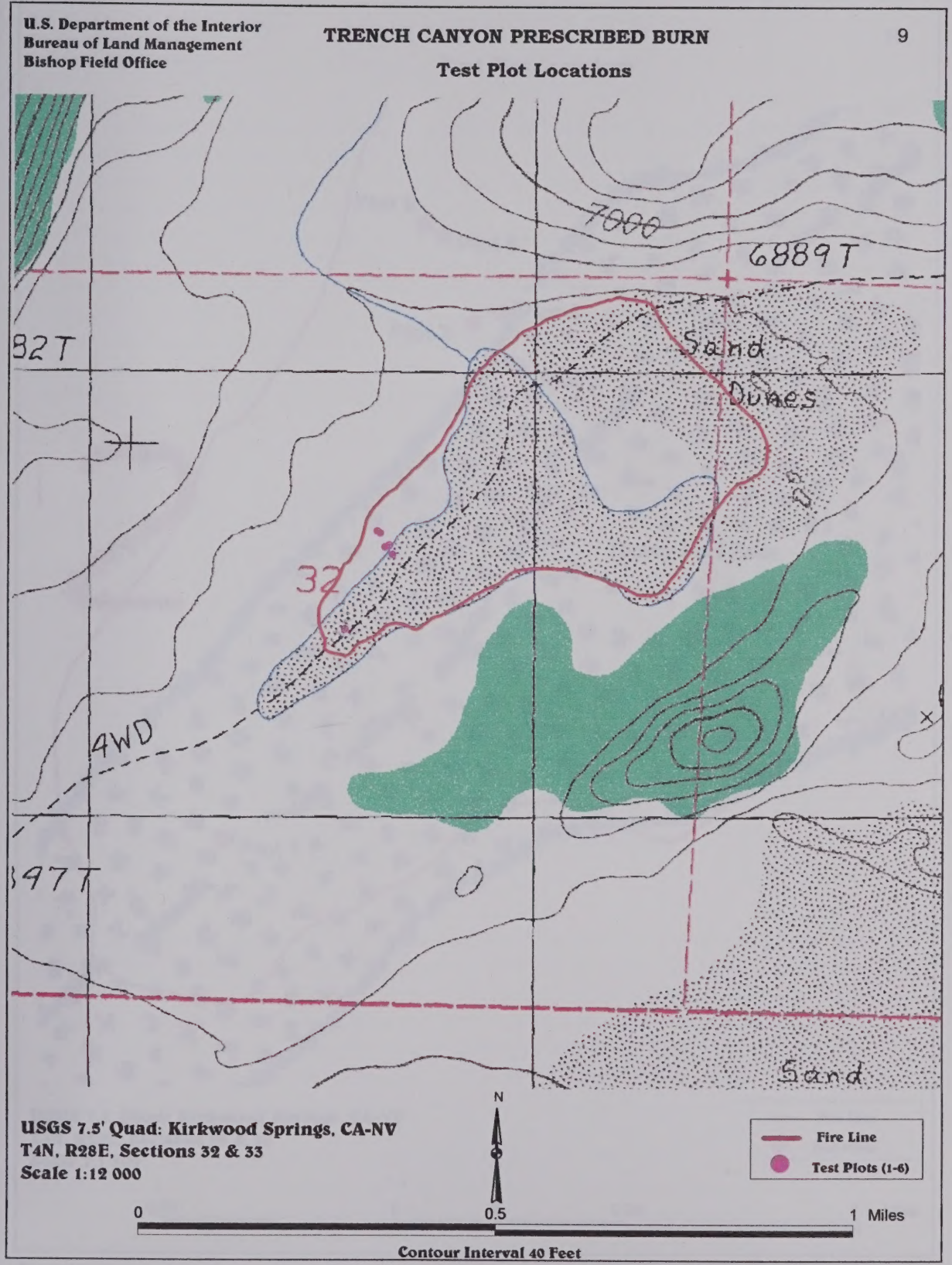

U.S. Department of the Interior
Bureau of Land Management
Bishop Field Office
TRENCH CANYON PRESCRIBED BURN
9
Test Plot Locations
7000
6889T
82T
Sand
Dunes
32
4WD
497T
Sand
N
USGS 7.5' Quad: Kirkwood Springs, CA-NV
T4N, R28E, Sections 32 & 33
Scale 1:12 000
Fire Line
Test Plots (1-6)
0
0.5
1 Miles
Contour Interval 40 Feet

Figure 5.

U.S. Department of the Interior
Bureau of Land Management
Bishop Field Office
TRENCH CANYON PRESCRIBED BURN
Test Plot Locations
10
Plot 6
Plot 5
Plot 4
Plot 3
Plot 2
Plot 1
Heavy Fuel Zone
USGS 7.5' Quad: Kirkwood Springs, CA-NV
T4N, R28E, Sections 32 & 33
Scale 1:1 500
N
Fire Line
Test Plots
0.05
0
0.05
0.1 Miles

Figure 6.

Obsidian Artifact Analyses

To test the research hypotheses, a sample of 180 obsidian artifacts (Appendix A) were distributed in the burn area within six, 1 m^2, test plots (Figures 5 and 6). Pre-burn obsidian hydration analyses were conducted by Pacific Legacy (specimens 1-140) and the Northwest Obsidian Research Laboratory (specimens 141-180). Each artifact was photocopied to facilitate post burn recovery. Thirty samples were distributed within every plot, ten each at the 0 cm, 5 cm and 10 cm levels (Figure 7). Test holes were excavated to the 10 cm level using a 8 cm diameter soil plug remover. The samples were arranged in three rows beginning from the northwest corner of the plot and placed numerically in a west to east sequence (Figure 7). Two plots each were placed within the three fuel types. Rebar designated the northwest corner of the plot. Each plot was mapped using a GPS unit on phase processor mode, providing submeter accuracy. All plots were set up one day prior to the burn.

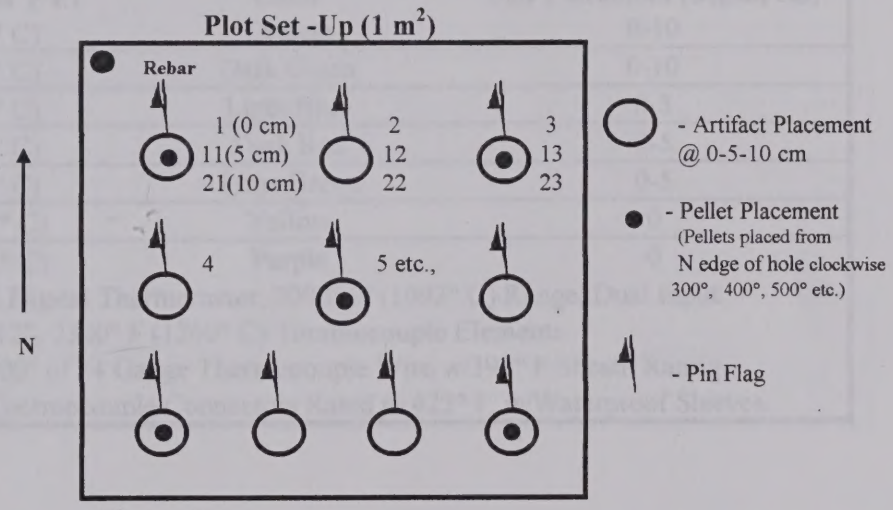
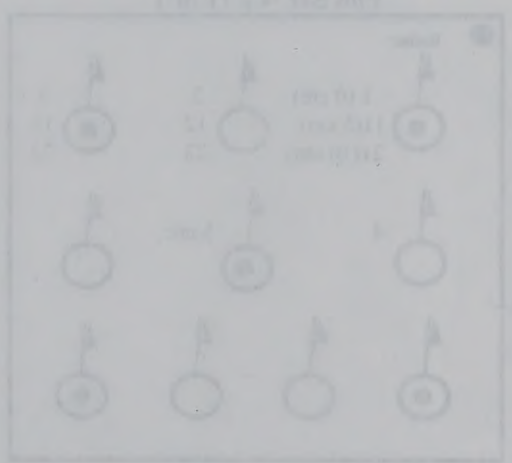


Figure 7.

Temperature measuring devices used to determine the fires heat intensity included Omega temperature pellets ranging from 300° F (149° C) to 1550° F (843° C) (Table 2). Each pellet was placed in a stainless steel cup and then situated in the northwest, northeast, center, southwest and southeast holes, with the artifacts located in the center (Figure 7). Pellets were arranged with the 300° pellet situated on the north edge of the hole and the remainder of the pellets distributed in a clockwise direction around the fringe of the hole. Table 2 shows the range of pellets utilized and their vertical placement. Three hundred and 400° pellets were placed in each level; 500°, 600°, and 900° from 0-5 cm; 1200° and 1550° only on the surface. A close range of pellets around 500° was employed (i.e., 300°, 400°, 600°) due to previous studies which indicate that 500° F appears to be the threshold at which the hydration rind is initially affected with serious effects occurring around 800° (Deal 1997; Trembour 1979). An Omega HH 12, dual input, handheld digital thermometer, with a 2000° F (1093° C) range, was used to record real time temperatures in Plot 1. Two 2300° (1260° C) thermocouple elements were



placed, one each, at the 0 cm and 5 cm levels in the center of the plot. Two hundred and fifty feet of thermocouple wire, with a sheath rating of 392° F (200° C), was laid at least 10 cm below the surface and strung along the fire break/road to the west end of the burn area where readings were collected every 30 seconds as the fire reached Plot 1.

A RAWS unit was placed at the study area one year prior to the burn. Data were collected hourly at the station and downloaded via satellite into data tables accessible by computer. Temperature, wind speed and direction, relative humidity and fuel moisture were monitored and utilized by the Bishop Field Office fire managers to develop a prescription for the Trench Canyon burn. Prescription parameters and burn day data are summarized in Table 3 and discussed in the following section.

Temperature Measuring Devices

Omega Pellets (°F)	Color	Plot Placement (depth, cm)
300° (149° C)	Orange	0-10
400° (204° C)	Dark Green	0-10
500° (260° C)	Light Blue	0-5
600° (315° C)	Dark Red	0-5
900° (482° C)	Lime Green	0-5
1200° (649° C)	Yellow	0
1550° (843° C)	Purple	0
* Omega HH 12 Digital Thermometer, 2000° F (1093° C) Range, Dual Input.		
* XC-24-K-12, 12", 2300° F (1260° C) Thermocouple Elements.		
* EXFF-K-24, 500' of 24 Gauge Thermocouple Wire w/392° F Sheath Rating.		
* SMP-K-MF, Thermocouple Connectors Rated to 425° F, w/Waterproof Sleeves.		

Table 2.

Results

The Burn Day

The prescribed burn was conducted late in the fall on November 20, 1998, by a Forest Service fire crew. On November 19, during plot set-up, it was noted that in the early morning the ground was covered with heavy frost and soils were frozen down to 10 cm in the Plots 1 and 2 within the heavy fuel zone. Table 3 summarizes the parameters developed for the fire prescription and burn data collected from the RAWS. As detailed in the table, burn day conditions did not fully fit within prescription parameters. Two key variables, wind speed and fuel moisture, were not within prescription. The fuel moisture for the 10 hour fuels, which can be equated with the smallest plants of the Great Basin sagebrush which dominates the project area, were four times (24.3%) above the prescribed percentage (6%).

The burn day was clear and cold in the morning with high cirrus clouds moving in over the Sierra. Burning began at 10:45 a.m. on the northeast edge of the project area within

moderate and light fuel zones. A team of 10 firefighters using drip torches began a strip burn procedure. Due to the low wind speed and the disperse nature of the fuels the fire was unable to carry. As a result, the fire needed to be carried by hand with burners lighting individual bushes as they moved in a line from east to west. Due to a lack of success in the moderate to light fuels, the burners moved into the heavy fuels at 12:00. In the heavy fuel zone the fire reached a hot enough intensity to completely consume much of the large brush and ground litter, but the firecrew was still compelled to carry the fire front by hand. By 14:00 the relative humidity began to rise causing the fire intensity to become much reduced and firecrew assisted burning was halted by 15:30.

Trench Canyon Prescribed Burn: Fire Prescription

Scheduling				**Burn Day**	
Total Burn Area Size	100 Acres			30 Acres	
Season	Fall			11-20-98	
Time of Day	0700-1300			1100-1500	
Acceptable Prescription Range					
	Low	**High**	**Desired**	**Low (time)**	**High (time)**
Temperature (°F)	50	80	70	10.0 (0638)	56.0 (1338)
Relative Humidity (%)	15	30	20	9.0 (1338)	61.0 (0638)
Night Time Recovery (%)	20	70	50	32.0 (1738 11-19-98)	61.0 (0638)
Mid-flame Wind Speed (mph)	8	20	10	2.0 (1138)	7.0 (1338)
Wind Direction	SW			SSE	SSE to SSW
Fuel Moisture (%)				**During Burn**	
1 Hour Fuels (< ¼" diameter)	4	5	4	6.1 (1338)	8.4 (1538)
10 Hour Fuels (¼ to 1" dia.)	4	6	4	24.3 (1438)	24.7 (1138)

Table 3.

Of the 100 acres scheduled for burning, 30 acres were successfully ignited (Figure 8). During the most intense period of the burn (at 13:00), flame lengths reached heights of 15 feet and most fuels were fully combusted. The fire was carried through test Plots 2-6 at 13:40 and reached Plot 1, at the northwest end of the project area, at 14:07, by which time the fire's intensity had begun to decrease dramatically. During the peak period of the fire, the heavy fuels (i.e., Great Basin sagebrush) burned hot and fast, with each bush burning intensely for roughly three minutes, consuming all of the leafy branches, leaving only remnant bases and smoldering roots. The fire left a mosaic effect with islands of fully consumed vegetation interspersed with partially burned and unaffected islands. Roots and bases of Great Basin sage continued to smolder through the following day. Stands of rabbitbrush were fully consumed and burned with a flashy, high intensity. In general, fuels within the project area can be classified as flashy fuels

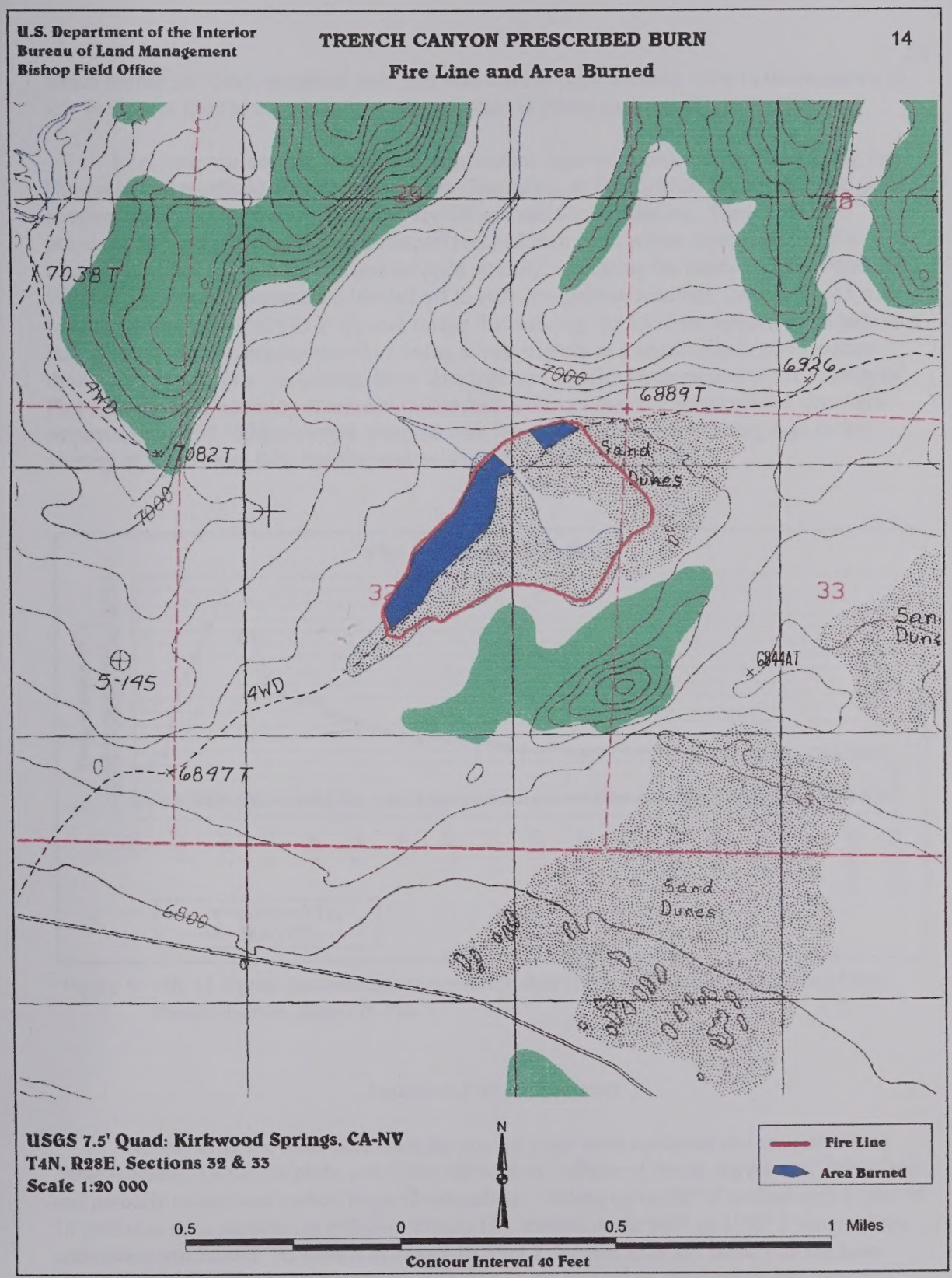
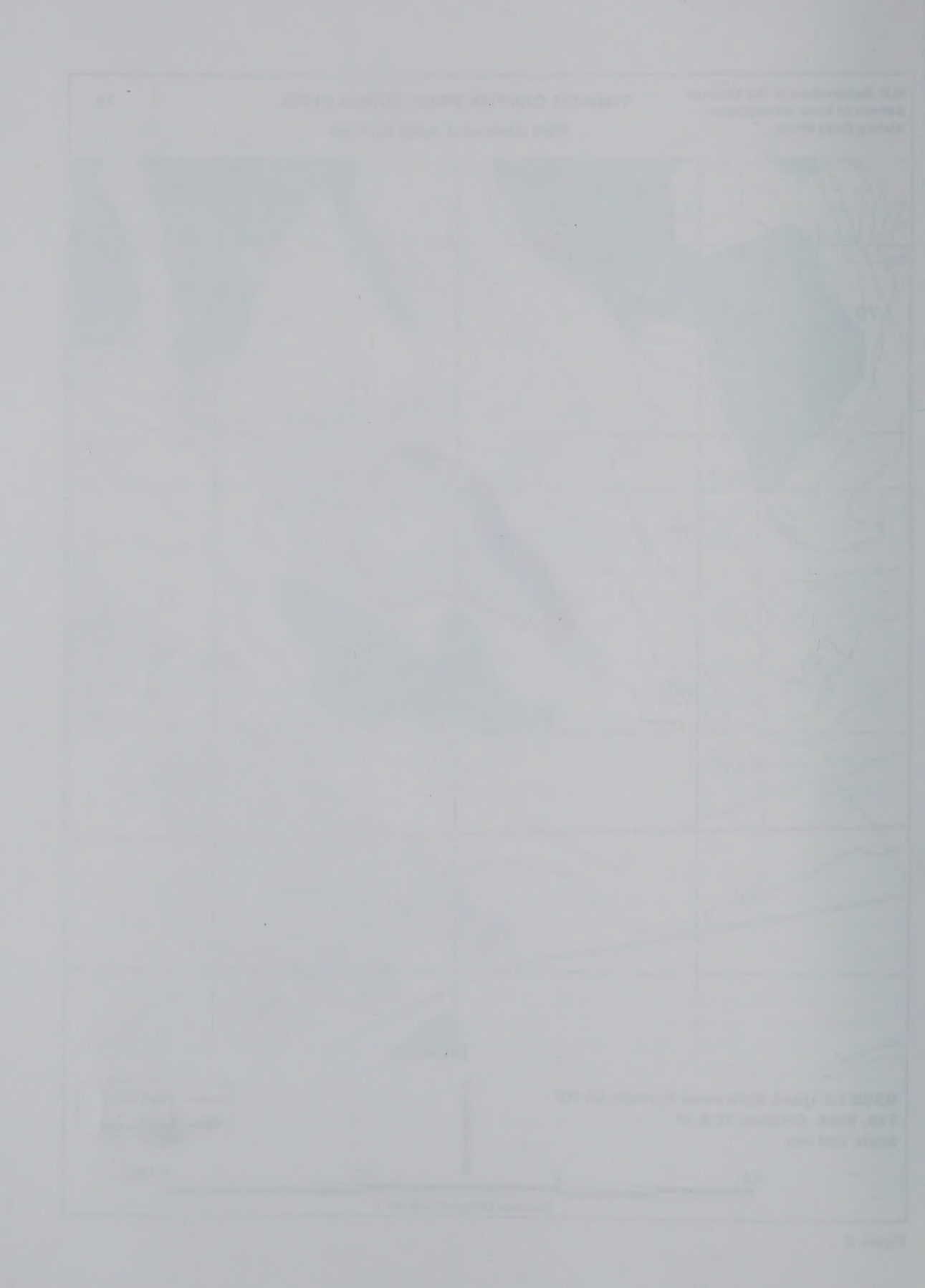

U.S. Department of the Interior
Bureau of Land Management
Bishop Field Office
TRENCH CANYON PRESCRIBED BURN
Fire Line and Area Burned
14
7038T
4WD
7082T
7000
6889T
6926
Sand Dunes
33
5-145
4WD
6847T
6844AT
6800
Sand Dunes
USGS 7.5' Quad: Kirkwood Springs, CA-NV
T4N, R28E, Sections 32 & 33
Scale 1:20 000
N
Fire Line
Area Burned
0.5
0
0.5
1 Miles
Contour Interval 40 Feet

Figure 8.



which burned for short periods of time, but with a fairly high intensity. Fire in the moderate to low fuel zones had to be carried from plant to plant to effect any type of combustion.

Real time, surface and subsurface, temperature data were collected in Plot 1 using the Omega HH 12 handheld digital thermometer. Beginning at 14:07, when fire reached the plot, temperatures readings were collected every :30 seconds for 25 minutes. These data are presented in Figure 9. Surface temperatures reached their peak within three minutes, at a maximum of 85.2° C (185.4° F), and dropped steadily, indicating the flashy nature of the fuels. Within 13 minutes, temperatures leveled off to near pre-ignition readings. Subsurface (5 cm) readings averaged 6.2° C (43.2° F) with minor fluctuations. At 55:30 an upward spike indicates that subsurface temperatures were beginning to rise slightly as a result of heat conductance through the sandy soils. In general, these data indicate low fire temperatures in the vicinity of Plot 1, resulting from rising relative humidity and cooler ambient air temperatures that were occurring by 14:00. These factors, coupled with low wind speeds, kept the big sage in the vicinity of Plot 1 from fully igniting and only reaching low temperatures.

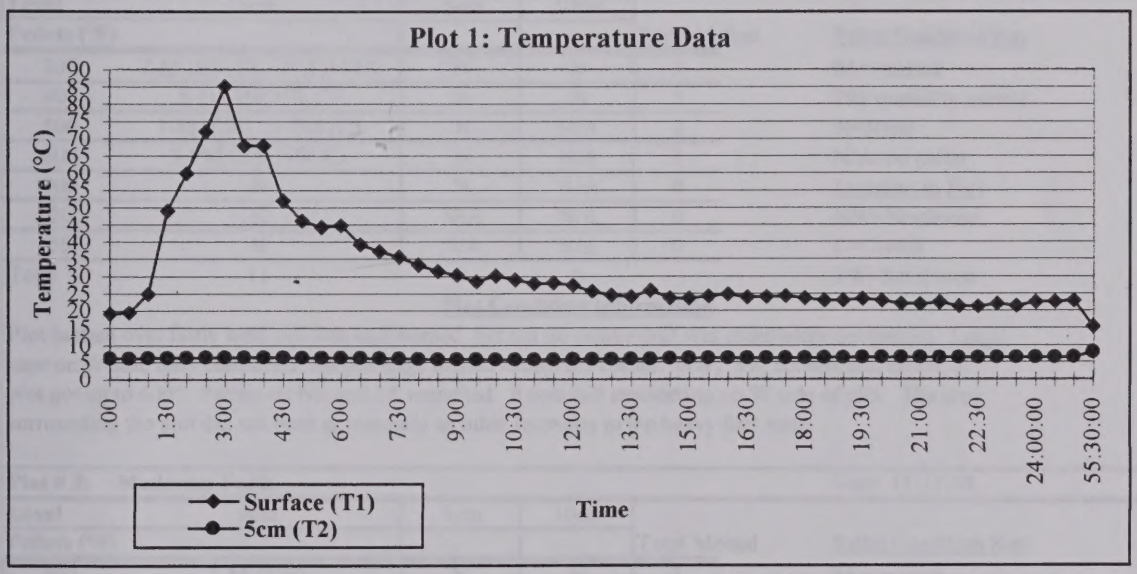


Figure 9. HH 12 digital thermometer temperature data from surface and subsurface (5 cm) thermocouples placed in Plot 1.

Post-Burn Plot Assessments

The day after the burn, data from the six test plots were collected and are outlined in Table 4 below. Of the six plots, only three showed any effects of fire in the form of burnt fuels and partially melted and melted temperature pellets. Pellets up to 600° F melted with a total of 18 pellets in three plots being effected (Figure 10). Pellets in the 900° to 1550° F ranges were completely unaffected. As shown in Figure 10, Plot 2, located in heavy fuels, was the most affected plot. Eleven pellets were melted (Table 4), all located on the western and central

Trench Canyon
Post Burn Plot Data

Plot # 1: Heavy Fuels Date: 11-21-98

Level	0cm	5cm	10cm		
Pellets (°F)				Total Melted	Pellet Condition Key
300	N	N	N	0	M = melted
400	N	N	N	0	PM=partially melted
500	N	N	N/A	0	N=None
600	N	N	N/A	0	N/A=no pellet
900	N	N	N/A	0	
1200	N	N/A	N/A	0	
1550	N	N/A	N/A	0	
Total	0	0	0		

Plot Condition Information

Vegetation in the plot appeared completely unburned, including fine and heavy duff. All pin flags were remaining, though the flags were melted and shriveled. No pellets on the surface were melted. Soils moist and frozen in some holes down to 5cm and moist to 10cm.

Plot # 2: Heavy Fuels Date: 11-21-98

Level	0cm	5cm	10cm		
Pellets (°F)				Total Melted	Pellet Condition Key
300	2-M (SW,C), 1PM (NW)	N	N	3	M = melted
400	3-M (SW,NW,C)	N	N	3	PM=partially melted
500	1-M (SW) , 1-PM (C)	N	N/A	2	N=None
600	3-PM (SW,NW,C)	N	N/A	3	N/A=no pellet
900	N	N	N/A	0	Location in Plot
1200	N	N/A	N/A	0	NW=Northwest
1550	N	N/A	N/A	0	C=Center
Total	11	0	0		SW=Southwest

Plot Condition Information

Plot burned over fairly well. All fine duff burned, but not all coarse duff was completely combusted. Large sage on W side fully consumed. All pin flags melted except SE corner. NW, SW corners and center of plot got up to 600°. Pellets on NE and SE unmelted. Roots still smoldering on W side of plot. The area surrounding the plot did not burn as intensely as other locations in the heavy fuel zone.

Plot # 3: Moderate Fuels Date: 11-21-98

Level	0cm	5cm	10cm		
Pellets (°F)				Total Melted	Pellet Condition Key
300	1-M (SW)	N	N	1	M = melted
400	1-M (SW)	N	N	1	PM=partially melted
500	2-PM (SW,SE)	N	N/A	2	N=None
600	1-PM (SW)	N	N/A	1	N/A=no pellet
900	N	N	N/A	0	Location in Plot
1200	N	N/A	N/A	0	SW=Southwest
1550	N	N/A	N/A	0	SE=Southeast
Total	5	0	0		

Plot Condition Information

Plot untouched except SW corner where a sage plant was partially burned and flags melted. Ricegrass and coarse duff on N side of plot unburned. Roughly 50% of vegetation on south side was burned. Heat remaining in sage roots. Pellets on surface melted to 600° in the SW corner near the sagebrush.

Table 4. Post burn plot data.

Trench Canyon
Post Burn Plot Data

Plot # 4: Moderate Fuels — Date: 11-21-98

Level / Pellets (°F)	0cm	5cm	10cm	Total Melted
300	N	N	N	0
400	N	N	N	0
500	N	N	N/A	0
600	N	N	N/A	0
900	N	N	N/A	0
1200	N	N/A	N/A	0
1550	N	N/A	N/A	0
Total	0	0	0	

Pellet Condition Key
M = melted
PM=partially melted
N=None
N/A=no pellet

Plot Condition Information

The plot was untouched by fire and no flags were burned. Vegetation within .5 meters of the S and E sides of the plot was 50% consumed, while 2 meters to the E all vegetation was burned. Three small obsidian specimens were lost at the 5cm level and 4 in the 10cm level due to sandy soils.

Plot # 5: Light Fuels — Date: 11-21-98

Level / Pellets (°F)	0cm	5cm	10cm	Total Melted
300	N	N	N	0
400	N	N	N	0
500	N/A	N/A	N/A	0
600	N	N	N/A	0
900	N	N/A	N/A	0
1200	N/A	N/A	N/A	0
1550	N/A	N/A	N/A	0
Total	0	0	0	

Pellet Condition Key
M = melted
PM=partially melted
N=None
N/A=no pellet

Plot Condition Information

The plot was unburned. Smaller vegetation (12" diameter) within .5 meters of the plot were burned. Fuels in this area are highly dispersed. Two small artifacts in the 5cm level were not recovered. Very sandy, well drained soils with low soil moisture.

Plot # 6: Light Fuels — Date: 11-21-98

Level / Pellets (°F)	0cm	5cm	10cm	Total Melted
300	2-PM (NW, SW)	N	N	2
400	N	N	N	0
500	N/A	N/A	N/A	0
600	N	N	N/A	0
900	N	N/A	N/A	0
1200	N/A	N/A	N/A	0
1550	N/A	N/A	N/A	0
Total	2	0	0	

Pellet Condition Key
M = melted
PM=partially melted
N=None
N/A=no pellet
Location in Plot
NW=Southwest
SW=Southeast

Plot Condition Information

All vegetation around the plot burned, including one large sagebrush located less than .5 meters to the east. All of the flags within the plot melted, but grasses within the plot were only marginally effected. The 300° pellets on the W side of the plot, near the sage that burned, partially melted.

Table 4. Post burn plot data.

portions of the plot where a large (1.5 m x 1.5 m) big sage was located. The large shrub along with coarse and fine duffs in the plot had combusted, though the coarse duffs were not fully consumed. The base of the large sage smoldered through the day. Plots 1 (heavy fuels), 4 (moderate fuels) and 5 (light fuels) were unaffected by the fire. A small sagebrush (< 0.5 m tall) on the southwest corner of Plot 3 was partially burned and pellets up to 600° were partially melted on the south edge of the plot (Table 4). A total of five pellets melted in this plot, four located in the southwest corner near the burnt sage. Plot 6 was the only other plot to be affected with two 300° pellets being partially melted on the west side of the site. This was caused by a sagebrush shrub which combusted .5 m to the west of the plot. These results show, in general, the moderate affect of the prescribed fire on the test plots.

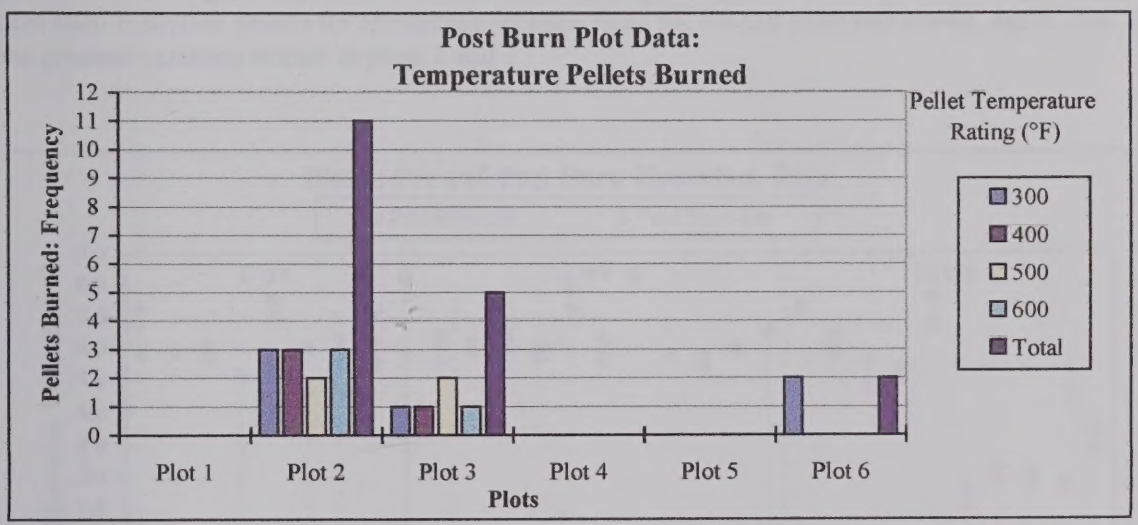


Figure 10.

Obsidian Artifact Analyses

Of the 180 artifacts planted in the six test plots, 172 (96%) were recovered. A total of eight subsurface artifacts were unrecovered in the light and moderate fuel zones due to small artifact size (< 1 cm diameter) and sandy soils. Use of a light mesh in each subsurface level could alleviate this problem. Due to the low intensity of the burn only 127 of the artifacts were submitted for post burn hydration analyses. Artifacts excluded were from unburned plots and mainly from the 10 cm level (Appendix A).

In general, due to the low intensity and duration of the burn very few artifacts were adversely affected. For this reason, other levels of variance were sought that may indicate fire effects. A paired t-test for dependent variables was used to assess inter-lab variability before assessing fire effects. Sixty one unaffected subsurface samples were tested, excluding six samples with diffuse hydration as outliers. The test showed a significant variance between pre and post burn hydration readings: Paired t-test, n = 61, Mean Difference = 0.306 μm, SD

Difference = 0.355 µm, t = 6.718, df = 60 , CI = 99%, p = < 0.001. Due to the significant level of inter-lab variability in hydration values only diffuse hydration and no visible band readings were used as a gauge of fire effects.

The results from Plot 2, the most intensively burned location, are shown in Figure 11. For the purposes of plotting hydration values, diffuse hydration was given a value of zero. As shown in Figure 11, four (40%) of ten surface artifacts show diffuse hydration indicating the effects of the fire on surface samples and no effect to subsurface samples, excluding specimen 50 as an outlier. Figure 12 shows the percentage of diffuse hydration for all surface samples from each plot and a pooled percentage for all subsurface specimens submitted for post burn analyses. Plots 2 and 3 were the most affected by the fire as indicated by both the number of pellets melted (Figure 10) and diffuse hydration readings. Figure13 shows plots of the pre and post burn hydration results for all surface samples from the six test plots and shows, again, that the greatest variation occurs in plots 2 and 3.

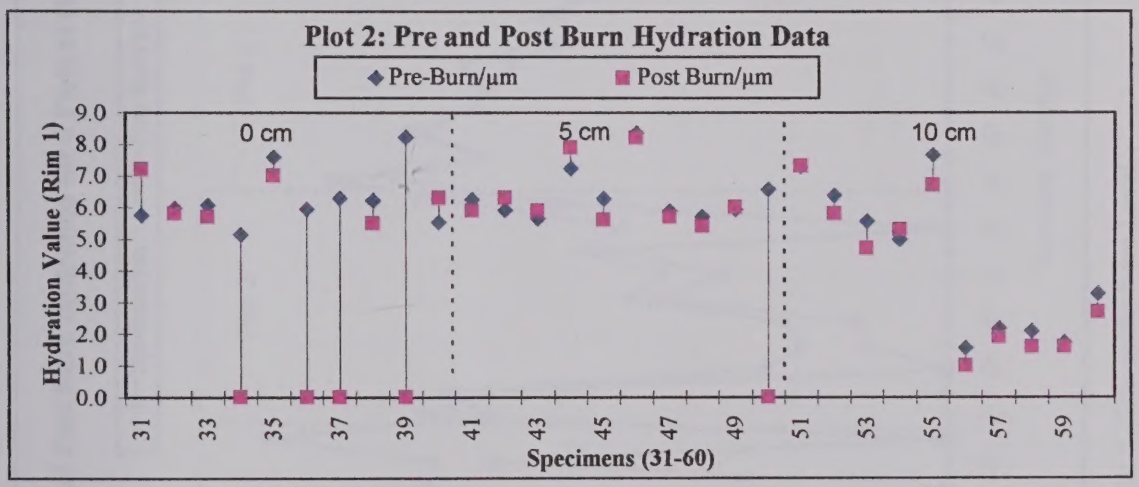


Figure 11.

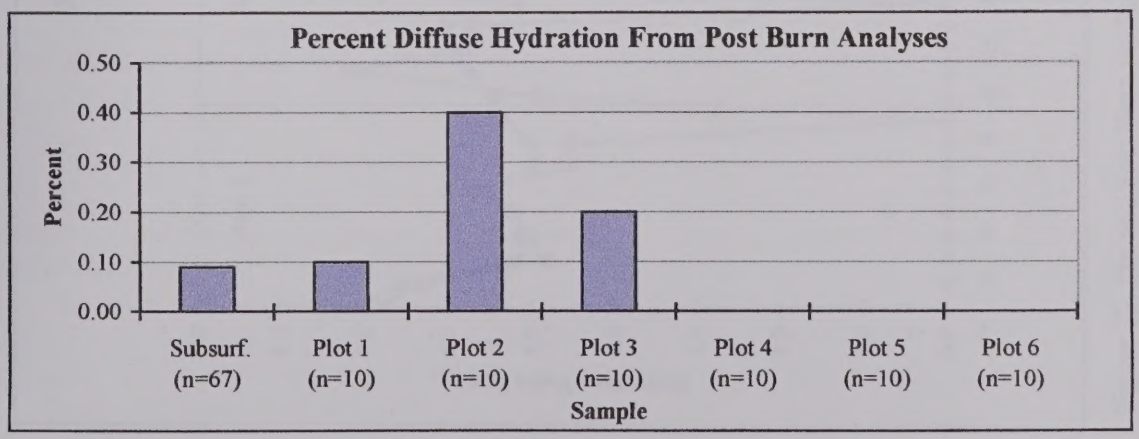
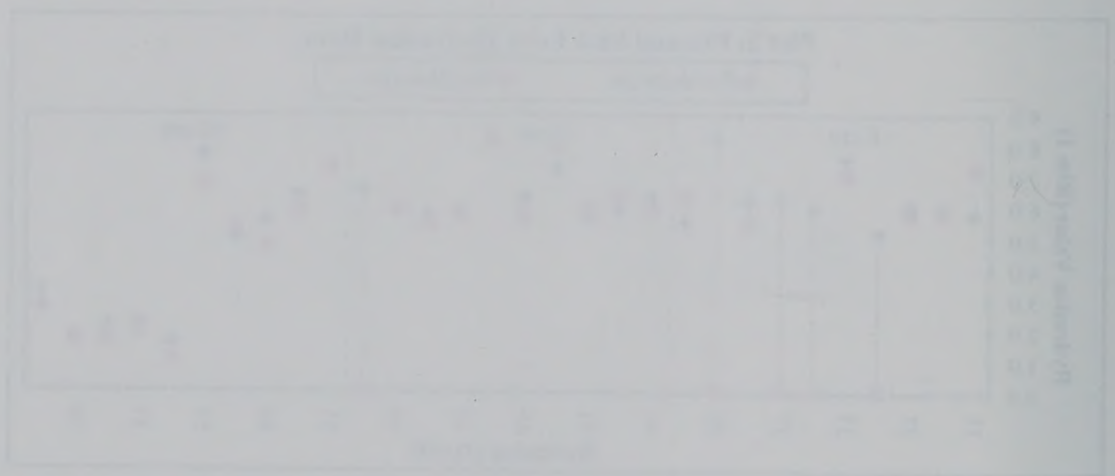


Figure 12.



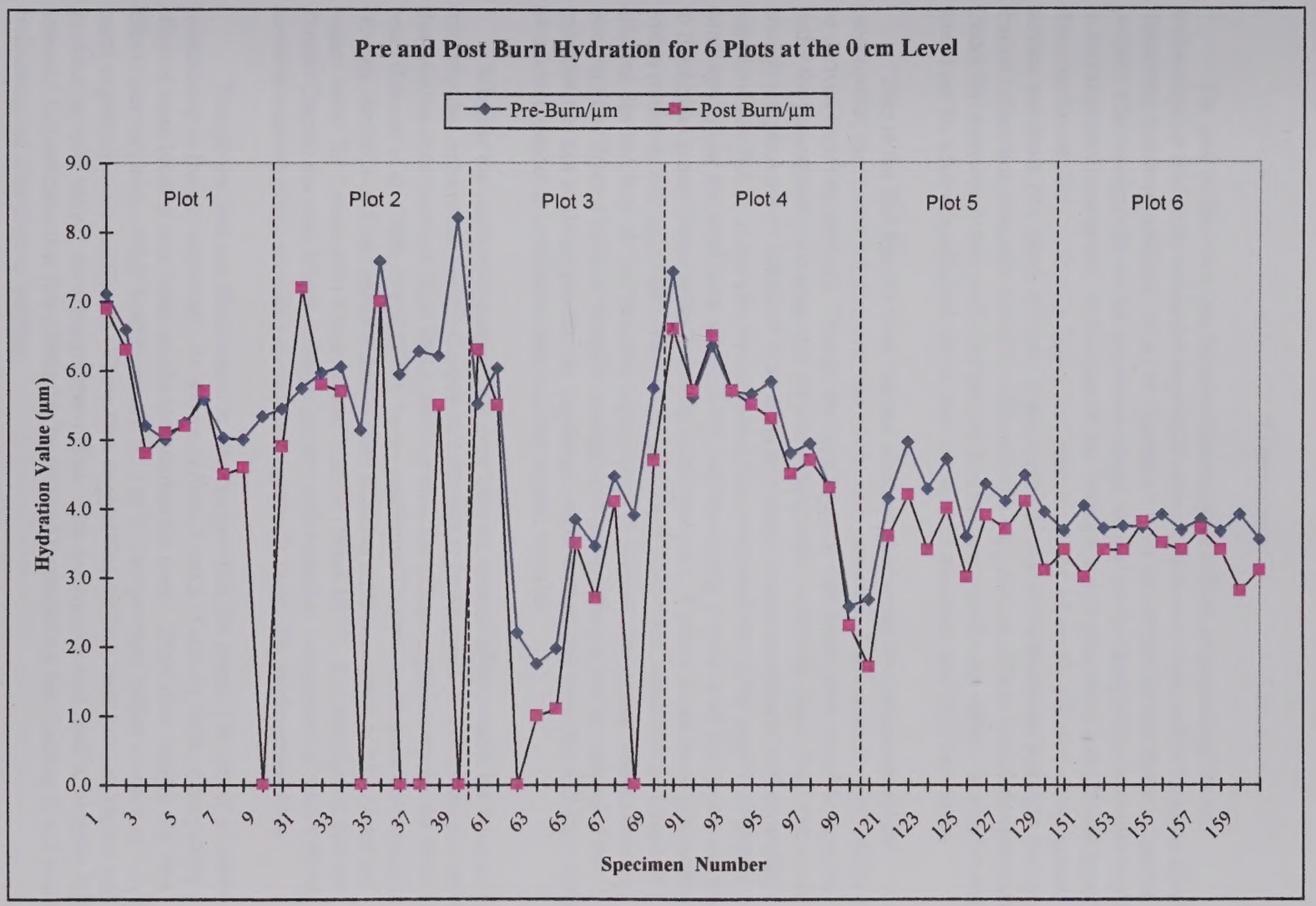


Figure 13. Pre and Post Burn Hydration for 6 Plots at the 0 cm Level.

Conclusions

The goal of this study has been to determine the effects of prescribed fire on archaeological resources within the sagebrush steppe community type, with a focus on obsidian flaked and tool stone artifacts. A set of hypotheses were developed for this study to test the premise that managed fire in the sagebrush steppe habitat can be designed to minimize impacts to archaeological resources. In the case of the Trench Canyon prescribed burn, it was expected that obsidian artifacts within the heavy fuel zone would be adversely affected on the ground surface and down to a depth of 5 cm. It was expected that in the moderate and light fuel types that no subsurface materials would be effected with only limited effects to surface specimens. Under this scenario, it was predicted that the five archaeological sites within the project area would not be adversely affected due to their location in moderate and light fuel zones.

Due to the fact that the burn was not accomplished under the parameters of the prescription, the research hypotheses can not be fully assessed. But important conclusions can be derived from this analysis. Though the burn intensity was lower than would be expected under the prescription, it is clear that surface temperatures within the heavy fuels can reach hot enough temperatures (> 400-500° F) to adversely impact hydration rinds of surface artifacts as was shown in Plot 2. It can also be concluded that prescribed fire in the sagebrush steppe, if conducted under the conditions of this event, will have little impact in all fuel types, and impacts to flaked and ground stone artifacts would be insignificant. Further, it can be suggested that sites within moderate and light fuels, even under prescribed conditions, would not be adversely affected due to a lack of fuel densities high enough to promote fire spread without human intervention. From a cultural resource management perspective, it can be concluded that prescriptions can be developed for the sagebrush steppe community type that will have limited to no adverse impact to prehistoric sites lacking organic remains.

Whether the vegetative goals of this burn have the desired affects under the reduced fire intensity that occurred at Trench Canyon still remains to be assessed. Previous studies indicate that postfire abundance of Great Basin wild rye does not change significantly for the first several years (Everett et al. 1984; Ward 1977). In big sagebrush/Thurber needlegrass communities in Nevada, densities of Great Basin wild rye were found to remain constant at 0.02 plants per square meter for 2 years after a mid-season wildfire (Ward 1977). It is anticipated that the Trench Canyon site will follow a similar pattern with regard to recruitment of new cohorts, however existing plants are likely to resprout vigorously under the implemented burn.

Though the data are not conclusive, they suggest that the spatial placement of artifacts in relationship to fuels is important. As shown in Plots 2 and 3 (Table 4), 94% of the pellets effected were located near burnt shrubs and smoldering roots. These data suggest that fire effects can vary even within limited areas (i.e., 1 m^2). Temperature pellets as close as 1 m from burnt vegetation were unaffected. These data suggest that artifacts near burning shrubs and smoldering roots should show the greatest effect. This assumption will need to be more fully assessed, but indicates that fire effects can be reduced by curtailing fuel loading in and around archaeological sites prior to burning.

As prescribed fire becomes more aggressively utilized to manage fire behavior and too attain desired ecosystem conditions, the effects of this management practice must be closely monitored for potential adverse affects to cultural resources. This study represents one prescribed burn, in one environmental context, under one set of weather conditions within the sagebrush steppe vegetation community in Trench Canyon, California. Fire behavior is complex, often unpredictable and ever changing and no one analysis can address all the variables that may influence a specific fire event and its effects to archaeological resources. But from this analysis it is clear that fire and cultural resource personnel can work together to develop prescribed fire parameters which can reduce the impacts to archaeological resources and in the long-term protect these resources by curtailing fuel loading which leads to both hot and long duration fire events.

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APPENDIX A

APPENDIX A

Trench Canyon Prescribed Burn: Artifact Data

TC Spec#	PL Spec#	Plot	Depth	CATALOG Cat. Number	Artifact Type	Pre-Burn/µm XRF	Mean	SO Spec#	Post Burn/µm	Remarks
1	11	1	0	95-14-S12-A1-22	Biface ST3 Mid.	TQ	7.1	1	6.9	none
2	12	1	0	95-14-S12-A3-23	Drill	TQ	6.6	2	6.3	none
3	14	1	0	95-14-S12-A5-27	Biface Edge Frag.		5.2	3	4.8	none
4	15	1	0	95-14-S12-12(F1)	Debitage	TQ	5.0	4	5.1	none
5	16	1	0	95-14-S12-12(F2)	Debitage		5.2	5	5.2	none
6	17	1	0	95-14-S12-12(F3)	Debitage		5.6	6	5.7	none
7	19	1	0	95-14-S12-14(F1)	Debitage	TQ	5.0	7	4.5	none
8	20	1	0	95-14-S12-14(F2)	Debitage		5.0	8	4.6	none
9	21	1	0	95-14-S12-14(F3)	Debitage		5.3	9	DH	weathered
10	22	1	0	95-14-S12-14(F4)	Debitage	TQ	5.4	10	4.9	none
11	23	1	5	95-14-S12-17(F1)	Debitage		6.5	11	NVB	weathered
12	24	1	5	95-14-S12-17(F2)	Debitage		5.9	12	5.4	none
13	27	1	5	95-14-S12-19(F1)	Debitage		5.1	13	4.9	none
14	28	1	5	95-14-S12-19(F2)	Debitage		5.6	14	5.2	none
15	29	1	5	95-14-S12-19(F3)	Debitage		5.2	15	4.7	none
16	30	1	5	95-14-S12-19(F4)	Debitage		5.6	16	5.2	none
17	31	1	5	95-14-S16-A2-14	Biface End Frag.		3.0	17	DH	none
18	32	1	5	95-14-S16-A1-5	Edge Modified Flake		2.2	18	DH	weathered
19	37	1	5	95-14-S16-8(F1)	Debitage		3.1	19	2.8	weathered
20	39	1	5	95-14-S16-8(F3)	Debitage		2.9	20	2.7	none
21	44	1	10	95-14-S20-9(F2)	Debitage		7.9	21	7.4	weathered
22	45	1	10	95-14-S20-A6-39	Debitage	TQ	4.9	22	4.6	none
23	46	1	10	95-14-S20-14(F1)	Debitage	TQ	6.1	23	DH	2 bands
									5.2	
24	47	1	10	95-14-S20-14(F2)	Debitage	TQ	6.0	24	5.7	weathered
25	48	1	10	95-14-S20-14(F3)	Debitage		6.7	25	6.0	weathered
26	50	1	10	95-14-S20-A4-19	Edge Modified Flake		6.3	26	6.4	none
27	51	1	10	95-14-S20-18(F1)	Debitage		6.6	27	6.5	none
28	52	1	10	95-14-S20-18(F2)	Debitage		5.0	28	5.6	none
							6.2			2nd rim
29	53	1	10	95-14-S20-18(F3)	Debitage		9.1	29	8.9	none
30	54	1	10	95-14-S20-18(F4)	Debitage		7.0	30	7.4	none
31	55	2	0	95-14-S20-28(F1)	Debitage		5.7	31	7.2	weathered
32	56	2	0	95-14-S20-28(F2)	Debitage		6.0	32	5.8	Band 2;w
									DH	2nd rim
33	59	2	0	95-14-S20-28(F5)	Debitage		6.1	33	5.7	none
							7.0			2nd rim
34	60	2	0	95-14-S20-28(F6)	Debitage	TQ	5.1	34	DH	weathered
35	61	2	0	95-14-S20-28(F7)	Debitage		7.6	35	7.0	none
36	62	2	0	95-14-S20-28(F8)	Debitage		5.9	36	DH	none
							7.0			2nd rim
37	63	2	0	95-14-S20-28(F9)	Debitage		6.3	37	DH	weathered
38	64	2	0	95-14-S20-30(F1)	Debitage		6.2	38	5.5	weathered
39	65	2	0	95-14-S20-30(F2)	Debitage		8.2	39	DH	2 bands; w
									DH	2nd rim
40	66	2	0	95-14-S20-30(F3)	Debitage		5.5	40	6.3	band 2; w
									VW	2nd rim
41	67	2	5	95-14-S20-30(F4)	Debitage		6.2	41	5.9	none
42	68	2	5	95-14-S20-30(F5)	Debitage	TQ	5.9	42	6.3	none
43	69	2	5	95-14-S20-30(F6)	Debitage		5.6	43	5.9	none
44	70	2	5	95-14-S20-30(F7)	Debitage		7.2	44	7.9	none
							7.8			2nd rim

APPENDIX A

Trench Canyon Prescribed Burn: Artifact Data

TC Spec#	PL Spec#	Plot	Depth	CATALOG Cat. Number	Artifact Type	Pre-Burn/µm XRF	Mean	SO Spec#	Post Burn/µm	Remarks
45	71	2	5	95-14-S20-30(F8)	Debitage		6.3	45	5.6	band 2; w
									DH	2nd rim
46	72	2	5	95-14-S20-30(F9)	Debitage		8.3	46	8.2	none
47	73	2	5	95-14-S21-A2-1	Core		5.9	47	5.7	none
48	74	2	5	95-14-S21-A3-2	Core		5.7	48	5.4	none
49	75	2	5	95-14-S21-3(F1)	Debitage		5.9	49	6.0	none
50	77	2	5	95-14-S21-3(F3)	Debitage		6.5	50	DH	band 1; w
									6.6	2nd rim
51	78	2	10	95-14-S21-5(F1)	Debitage		7.3	51	7.3	none
52	79	2	10	95-14-S21-5(F2)	Debitage		6.4	52	5.8	none
53	80	2	10	95-14-S21-5(F3)	Debitage		5.6	53	4.7	none
54	81	2	10	95-14-S21-5(F4)	Debitage		5.0	54	5.3	none
55	82	2	10	95-14-S21-5(F5)	Debitage		7.6	55	6.7	none
56	83	2	10	95-14-S36-A1-7	Core		1.5	56	1.0	none
57	84	2	10	95-14-S36-A6-3	Core		2.2	57	1.9	none
58	85	2	10	95-14-S36-A7-8	Core	TQ	2.1	58	1.6	none
59	86	2	10	95-14-S36-A8-9	Core	TQ	1.7	59	1.6	none
60	87	2	10	95-14-S36-2	Debitage	TQ	3.3	60	2.7	none
61	88	3	0	95-14-S36-4	Debitage		6.0	61	5.5	none
62	90	3	0	95-14-S36-A4-6(F1)	Core		2.2	62	DH	weathered
63	91	3	0	95-14-S36-A4-6(F2)	Core	TQ	1.7	63	1.0	none
64	92	3	0	95-14-S36-A4-6(F3)	Core		2.0	64	1.1	none
65	95	3	0	95-14-S38-A12-19	Biface End Frag.		3.8	65	3.5	weathered
66	97	3	0	95-14-S38-1(F1)	Debitage		3.5	66	2.7	none
67	99	3	0	95-14-S38-6(F1)	Debitage		4.5	67	4.1	none
68	100	3	0	95-14-S38-6(F2)	Debitage		3.9	68	DH	weathered
69	101	3	0	95-14-S38-6(F3)	Debitage		5.7	69	4.7	none
70	103	3	0	95-14-S44-A1-2	Edge Modified Flake		7.4	70	6.6	weathered
71	105	3	5	95-14-S44-A4-4	Biface ST3	TQ	5.7	71	5.8	none
72	106	3	5	95-14-S44-A5-5	Formed Flake Tool	TQ	5.5	72	5.0	none
73	107	3	5	95-14-S44-10(F1)	Debitage		4.8	73	5.0	none
74	108	3	5	95-14-S44-10(F2)	Debitage	TQ	5.7	74	5.2	none
75	109	3	5	95-14-S44-10(F3)	Debitage		5.6	75	4.7	weathered
76	111	3	5	95-14-S44-10(F5)	Debitage		5.7	76	5.2	none
77	112	3	5	95-14-S44-10(F6)	Debitage		5.5	77	4.7	band 2; w
									5.2	2nd rim
78	113	3	5	95-14-S44-11(F1)	Debitage		5.4	78	4.8	none
79	114	3	5	95-14-S44-11(F2)	Debitage	TQ	7.3	79	7.0	none
80	115	3	5	95-14-S44-11(F3)	Debitage		7.0	80	6.7	none
81	116	3	10	95-14-S44-11(F4)	Debitage		5.0	N/A		
82	117	3	10	95-14-S44-11(F5)	Debitage		5.0	N/A		
83	118	3	10	95-14-S44-11(F6)	Debitage		5.6	N/A		
84	119	3	10	95-14-S44-21(F1)	Debitage		4.9	N/A		
85	121	3	10	95-14-S44-21(F3)	Debitage		6.1	N/A		
							8.7			2nd rim
86	123	3	10	95-14-S44-23(F1)	Debitage		5.7	N/A		
87	124	3	10	95-14-S44-23(F2)	Debitage		5.5	N/A		
88	125	3	10	95-14-S44-23(F3)	Debitage		5.7	N/A		
89	126	3	10	95-14-S44-23(F4)	Debitage		5.3	N/A		
90	127	3	10	95-14-S44-23(F5)	Debitage		5.0	N/A		
							5.9			2nd rim
91	128	4	0	95-14-S44-24(F1)	Debitage		5.6	81	5.7	weathered

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Trench Canyon Prescribed Burn: Artifact Data

TC Spec#	PL Spec#	Plot	Depth	CATALOG Cat. Number	Artifact Type	Pre-Burn/µm XRF	Pre-Burn/µm Mean	SO Spec#	Post Burn/µm	Remarks
92	129	4	0	95-14-S44-24(F2)	Debitage		6.3	82	6.5	none
93	130	4	0	95-14-S44-24(F3)	Debitage		5.7	83	5.7	none
94	131	4	0	95-14-S44-24(F4)	Debitage		5.7	84	5.5	none
95	132	4	0	95-14-S44-24(F5)	Debitage		5.8	85	5.3	none
96	133	4	0	95-14-S51-A1-8	Biface Edge Frag.		4.8	86	4.5	band 2: w
									4.6	2nd rim
97	134	4	0	95-14-S51-A3-19	Biface Edge Frag.		4.9	87	4.7	none
98	135	4	0	95-14-S51-A4-21	Edge Modified Flake		4.3	88	4.3	band 2; w
									4.4	2nd rim
99	136	4	0	95-14-S51-1(F1)	Debitage		2.6	89	2.3	none
100	137	4	0	95-14-S51-1(F2)	Debitage		2.7	90	1.7	none
101	139	4	5	95-14-S51-2(F1)	Debitage		1.8	91	1.1	none
102	141	4	5	95-14-S51-2(F3)	Debitage		2.6	92	2.3	none
103	142	4	5	95-14-S51-2(F4)	Debitage		2.7	93	2.4	none
104	143	4	5	95-14-S51-2(F5)	Debitage		2.3	N/A		
105	144	4	5	95-14-S51-2(F6)	Debitage		3.1	N/A		
106	146	4	5	95-14-S51-3(F1)	Debitage		2.3	94	1.6	none
107	147	4	5	95-14-S51-3(F2)	Debitage		2.1	95	1.9	none
108	154	4	5	95-14-S52-A2-2	Biface ST3	TQ	3.5	96	3.0	none
109	156	4	5	95-14-S52-A5-14	Edge Modified Flake	MC	6.3	97	5.4	none
110	157	4	5	95-14-S52-4(F1)	Debitage		3.2	N/A		
111	158	4	10	95-14-S52-4(F2)	Debitage		3.4	N/A		
112	159	4	10	95-14-S52-4(F3)	Debitage		3.1	N/A		
113	160	4	10	95-14-S52-4(F4)	Debitage		4.8	N/A		
114	163	4	10	95-14-S52-4(F7)	Debitage		4.1	N/A		
115	165	4	10	95-14-S52-7(F1)	Debitage		3.1	N/A		
116	167	4	10	95-14-S52-7(F3)	Debitage		4.8	N/A		
117	168	4	10	95-14-S52-7(F4)	Debitage		4.1	N/A		
118	172	4	10	95-14-S52-7(F8)	Debitage		3.9	N/A		
119	173	4	10	95-14-S62-A1-16	Edge Modified Flake	TQ	4.1	N/A		
120	174	4	10	95-14-S62-A2-17	Biface Edge Frag.		3.4	N/A		
121	175	5	0	95-14-S62-A3-18	Biface Edge Frag.		4.1	98	3.6	weathered
122	176	5	0	95-14-S62-1(F1)	Debitage	TQ	5.0	99	4.2	none
123	177	5	0	95-14-S62-1(F2)	Debitage		4.3	10	3.4	none
124	178	5	0	95-14-S62-1(F3)	Debitage		4.7	101	4.0	none
125	179	5	0	95-14-S62-1(F4)	Debitage	TQ	3.6	102	3.0	band 2; w
									VW	2nd rim
126	180	5	0	95-14-S62-1(F5)	Debitage		4.4	103	3.9	weathered
127	181	5	0	95-14-S62-1(F6)	Debitage		4.1	104	3.7	none
128	182	5	0	95-14-S62-1(F7)	Debitage	TQ	4.5	105	4.1	none
129	183	5	0	95-14-S62-1(F8)	Debitage		3.9	106	3.1	weathered
130	184	5	0	95-14-S62-1(F9)	Debitage		3.7	107	3.4	weathered
131	185	5	5	95-14-S62-1(F10)	Debitage	TQ	3.6	N/A		
132	186	5	5	95-14-S62-4(F1)	Debitage		3.8	N/A		
133	187	5	5	95-14-S62-4(F2)	Debitage		4.0	N/A		
134	188	5	5	95-14-S62-4(F3)	Debitage		3.8	N/A		
135	189	5	5	95-14-S62-4(F4)	Debitage		4.0	N/A		
136	190	5	5	95-14-S62-4(F5)	Debitage		3.9	N/A		
137	191	5	5	95-14-S62-4(F6)	Debitage		3.7	N/A		
138	192	5	5	95-14-S62-4(F7)	Debitage		3.7	N/A		
139	196	5	5	95-14-S29-A4-23	CTN	TQ	2.7	N/A		
140	198	5	5	95-14-I53	RSG	TQ	3.4	N/A		

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Trench Canyon Prescribed Burn: Artifact Data

TC Spec#	NW Spec#	Plot	Depth	CATALOG Cat. Number	Artifact Type	Pre-Burn/µm XRF	Mean	SO Spec#	Post Burn/µm	Remarks
141	1	5	10	97-29-S1-A1	ELK PP Midsection	CD	6.1	N/A		
142	2	5	10	97-29-S1-A2	PP Midsection	SP	5.7	N/A		
143	3	5	10	97-29-S3-F1	Debitage	MH	3.2	N/A		
144	4	5	10	97-29-S3-F2	Debitage	MH	4.2	N/A		
						2nd rim	12.2			
145	5	5	10	97-29-S3-F3	Debitage	MH	3.6	N/A		
146	6	5	10	97-29-S3-F4	Debitage	MH	3.9	N/A		
147	7	5	10	97-29-S3-F5	Debitage	MH	3.8	N/A		
148	8	5	10	97-29-S3-F6	Debitage	MH	3.6	N/A		
149	9	5	10	97-29-S3-F7	Debitage	BH	7.1	N/A		
						2nd rim	9.0			
150	10	5	10	97-29-S3-F8	Debitage	MH	3.3	N/A		
151	11	6	0	97-29-S3-F9	Debitage	MH	4.0	108	3.0	weathered
152	12	6	0	97-29-S3-F10	Debitage	MH	3.7	109	3.4	weathered
153	13	6	0	97-29-S3-F11	Debitage		3.7	110	3.4	weathered
154	14	6	0	97-29-S3-F12	Debitage		3.7	111	3.8	none
155	15	6	0	97-29-S3-F13	Debitage		3.9	112	3.5	band 2; w
									DH	2nd rim
156	16	6	0	97-29-S3-F14	Debitage		3.7	113	3.4	band 2; w
									DH	2nd rim
157	17	6	0	97-29-S3-F15	Debitage		3.8	114	3.7	weathered
158	18	6	0	97-29-S3-F16	Debitage		3.7	115	3.4	none
159	19	6	0	97-29-S3-F17	Debitage		3.9	116	2.8	none
160	20	6	0	97-29-S3-F18	Debitage		3.5	117	3.1	weathered
161	21	6	5	97-29-S3-F19	Debitage		3.5	118	3.3	none
162	22	6	5	97-29-S3-F20	Debitage		3.9	119	3.2	none
163	23	6	5	97-29-S3-F21	Debitage		3.7	120	3.6	none
164	24	6	5	97-29-S3-F22	Debitage		3.7	121	3.5	band 2; w
									DH	2nd rim
165	25	6	5	97-29-S3-F23	Debitage		3.5	122	3.0	band 2; w
									3.1	2nd rim
166	26	6	5	97-29-S3-F24	Debitage		3.7	123	3.5	none
167	27	6	5	97-29-S3-F25	Debitage		3.7	124	3.4	band 1; w
									3.7	2nd rim
168	28	6	5	97-29-S3-F26	Debitage		3.7	125	DH	weathered
169	29	6	5	97-29-S3-F27	Debitage		3.7	126	3.2	band 2; w
									3.2	2nd rim
170	30	6	5	97-29-S3-F28	Debitage		3.7	127	3.1	none
171	31	6	10	97-29-S3-F29	Debitage		3.5	N/A		
172	32	6	10	97-29-S3-F30	Debitage		3.7	N/A		
173	33	6	10	97-29-S4-A1	RSG PP	BH	4.4	N/A		
						2nd rim	3.5			
174	34	6	10	97-29-S4-A2	ST4 Biface End Frag.	CD	6.9	N/A		
175	35	6	10	97-29-S4-A3	Dart PP Tip	MH	7.7	N/A		
176	36	6	10	97-29-S5-F1	Debitage	MH	3.3	N/A		
177	37	6	10	97-29-S5-F2	Debitage	MH	3.6	N/A		
178	38	6	10	97-29-S5-F3	Debitage	MH	3.3	N/A		
179	39	6	10	97-29-S5-F4	Debitage	MH	3.3	N/A		
180	40	6	10	97-29-S5-F5	Debitage	MH	3.3	N/A		
181	41	N/A		97-29-S5-F6	Debitage	MH	10.2	N/A		
182	42	N/A		97-29-S5-F7	Debitage	MH	7.2	N/A		

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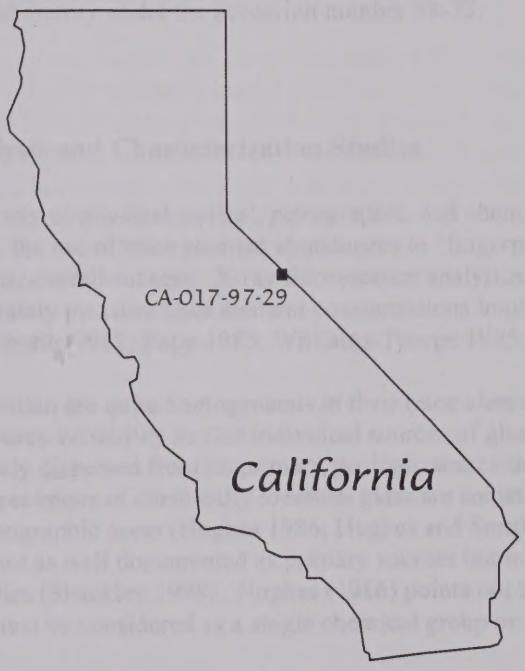
Trench Canyon Prescribed Burn: Artifact Data

TC Spec#	NW Spec#	Plot	Depth	CATALOG Cat. Number	Artifact Type	Pre-Burn/µm XRF	Mean	SO Spec#	Post Burn/µm	Remarks
183	43	N/A		97-29-S5-F8	Debitage	MH	6.6	N/A		
184	44	N/A		97-29-S5-F9	Debitage	MH	9.0	N/A		
185	45	N/A		97-29-S5-F10	Debitage	MH	8.2	N/A		
						2nd rim	54.2			

TC=Trench Canyon; PL=Pacific Legacy; NW=Northwest Research Obsidian Studies Lab; SO=Sonoma State Obsidian Hydration Lab; DH=Diffuse Hydration band; NVB=No Visible Band; VW=Variable Width; W=Weathered or Corroded.

APPENDIX B

X-Ray Fluorescence Analysis and Obsidian Hydration Rim Measurement of Artifact Obsidian from the Trench Canyon Site (CA-017-97-29), Mono County, California



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Northwest Research Obsidian Studies Laboratory Report 98-73

X-Ray Fluorescence Analysis and Obsidian Hydration Rim Measurement of Artifact Obsidian from the French Canyon Site (CA-Mno-729), Mono County, California

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NWRS Northwest Research Obsidian Studies Laboratory Report 98-23

X-Ray Fluorescence Analysis and Obsidian Hydration Rim Measurement of Artifact Obsidian from the Trench Canyon Site (CA-017-97-29), Mono County, California

Introduction

Twenty-five obsidian artifacts from the Trench Canyon Site (CA-017-97-29), Mono County, California, Oregon were submitted for energy dispersive X-ray fluorescence trace element provenience analysis. A total of 45 samples, including all those submitted for trace element studies, were also processed for obsidian hydration rim measurements. The samples were prepared and analyzed at the Northwest Research Obsidian Studies Laboratory under the accession number 98-73.

Analytical Methods

X-Ray Fluorescence Analysis and Characterization Studies

Introduction. Although a variety of physical, optical, petrographic, and chemical attributes are used to characterize volcanic glasses, the use of trace element abundances to "fingerprint" obsidian sources and artifacts has shown the greatest overall success. X-ray fluorescence analytical methods, with their ability to nondestructively and accurately measure trace element concentrations in obsidian, have been widely adopted for this purpose (Harbottle 1982; Rapp 1985; Williams-Thorpe 1995; Glascock et al. 1998).

Most geologic sources of obsidian are quite homogeneous in their trace element composition, yet demonstrate adequate intersource variability so that individual sources of glass can be distinguished. Because obsidian can be widely dispersed from its primary geologic source due to a variety of geologic and geomorphic processes, specimens of chemically identical glass are sometimes recovered from outcrops spread over large geographic areas (Hughes 1986; Hughes and Smith 1993). These secondary source boundaries are often not as well documented as primary sources but must be carefully considered in obsidian procurement studies (Shackley 1998). Hughes (1986) points out that these chemically identical obsidian outcrops must be considered as a single chemical group or chemical type and his terminology is followed here.

From small scale (household and site) to large scale (regional and interregional) levels of analysis, the spatial source patterning of characterized obsidian artifacts is influenced by many different environmental and cultural factors. Interpretation of these patterns can provide valuable information about the prehistoric behavioral and environmental procurement variables responsible for observed artifact distributions. At the site level of analysis, patterns of source use may suggest the presence of specific activity areas, of single tool manufacturing events, or, in special cases, may point to differential access of goods and the existence of non-egalitarian social structures. At the intersite or regional level of investigation, the geographic patterning of artifacts can provide information about seasonal procurement ranges, territorial and ethnic boundaries, the location of trails and travel routes, the curational value of particular sources or formal artifact types, cultural preferences regarding glass quality and colors, the presence of trade and exchange systems, the existence of intergroup interaction, and the exchange of prestige items between elites of different groups (Ericson 1981; Hughes 1978, 1990; Hughes and Bettinger 1984). The effects of environmental influences such as the distance to source, the location of alternative or competing sources of lithic materials, the distribution of raw materials in secondary

deposits, or the presence of potential barriers such as mountain ranges, must all be considered. Bias introduced during sampling by certain recovery methods, artifact size, and the use of small numbers of samples may also affect the reconstruction of the spatial patterning of analyzed artifacts.

Sample Preparation Methods. Obsidian samples selected for X-ray fluorescence analysis are typically restricted to clean artifacts (a wash with tap water and a brush will usually suffice) with a relatively flat surface at least 10 mm in diameter and at least 1.5 mm thick. Although it is possible to analyze slightly smaller samples (7-10 mm in diameter and 0.5-1.0 mm thick), these items will show some distortion in trace element values and may not be able to be reliably characterized. This is particularly true in areas with complex source use patterns. Source assignments of samples that do not meet the minimum reliable size criteria of 10 mm diameter and 1.5 mm thickness, and/or show distorted trace element values are indicated by an asterisk in the data tables that appear in the Appendix.

Analytical Methods. Analysis of the samples was completed using a Spectrace 5000 energy dispersive X-ray fluorescence spectrometer. The system is equipped with a Si(Li) detector with a resolution of 155 eV FHWM for 5.9 keV X-rays (at 1000 counts per second) in an area 30 mm^2. Signals from the spectrometer are amplified and filtered by a time variant pulse processor and sent to a 100 MHZ Wilkinson type analog-to-digital converter. The X-ray tube employed is a Bremsstrahlung type, with a rhodium target, and 5 mil Be window. The tube is driven by a 50 kV 1 mA high voltage power supply, providing a voltage range of 4 to 50 kV. The principles of X-ray fluorescence analytical methods are reviewed in detail by Norrish and Chappell (1967), Potts and Webb (1992), and Williams (1987). X-ray fluorescence analytical procedures used in the analysis of all obsidian samples were originally developed by M. Kathleen Davis (BioSystems Analysis and Northwest Research Obsidian Studies Laboratory).

For analysis of the elements zinc (Zn), lead (Pb), thorium (Th), rubidium (Rb), strontium (Sr), yttrium (Y), zirconium (Zr), and niobium (Nb), the X-ray tube is operated at 30 kV, 0.30 mA (pulsed), with a 0.127 mm Pd filter. Analytical lines used are Zn (K-alpha), Pb (L-alpha), Th (L-alpha), Rb (K-alpha), Sr (K-alpha), Y (K-alpha), Zr (K-alpha) and Nb (K-alpha). Samples are scanned for 200 seconds live-time in an air path.

Peak intensities for the above elements are calculated as ratios to the Compton scatter peak of rhodium, and converted to parts-per-million (ppm) by weight using linear regressions derived from the analysis of twenty rock standards from the U.S. Geological Survey, the Geologic Survey of Japan, and the National Bureau of Standards. The analyte to Compton scatter peak ratio is employed to correct for variation in sample size, surface irregularities, and variation in the sample matrix.

For analysis of the elements titanium (Ti), manganese (Mn), and iron ($Fe_2O_3^T$), the X-ray tube is operated at 12 kV, 0.27 mA with a 0.127 mm aluminum filter. Samples are scanned for 200 seconds live-time in a vacuum path. Analytical lines used are Ti (K-alpha), Mn (K-alpha), and Fe (K-alpha).

Concentration values (parts per million for titanium and manganese, weight percent for iron) are calculated using linear regressions derived from the analysis of thirteen standards from the U.S. Geological Survey, the Geologic Survey of Japan and the National Bureau of Standards. However, these values are *not* corrected against the Compton scatter peak or other scatter regions, resulting in lower than normal trace element values for small samples that fall below the minimum size requirement. Iron/titanium (Fe/Ti) and iron/manganese (Fe/Mn) peak ratios are supplied for use as corrected values. To ensure comparability among samples of different sizes, source assignments in all reports are based upon these ratios, and not on the absolute concentration values.

For analysis of the elements barium (Ba), lanthanum (La) and cerium (Ce), the X-ray tube is operated at 50 kV, 0.25 mA with a 0.63 mm copper filter in the X-ray path. Analytical lines used are Ba (K-alpha), La (K-alpha), and Ce (K-alpha). Samples are scanned in an air path for 100 to 600 seconds live-time, depending upon trace element concentration. Trace element intensities are calculated as ratios to the Bremsstrahlung region between 25.0 and 30.98 keV, and converted to parts-per-million by weight using a polynomial fit routine derived from the analysis of sixteen rock standards from the U.S. Geological Survey and the Geologic Survey of Japan. It should be noted that the Bremsstrahlung region corrects for sample mass only and does not account for matrix effects.

All samples are scanned as unmodified rock specimens. Reported errors represent counting and fitting error uncertainty only, and do not account for instrumental precision or effects related to the analysis of unmodified obsidian. When the latter effects are considered, relative analytical uncertainty is estimated to be between three and five percent.

In traditional X-ray fluorescence trace element studies, samples are powdered and pelletized before analysis (Norrish and Chappell 1967; Potts and Webb 1992). In theory, the irregular surfaces of most obsidian artifacts should induce measurement problems related to shifts in artifact-to-detector reflection geometry (Hughes 1986:35). Early experiments with intact obsidian flakes by Robert N. Jack, and later by Richard Hughes, however, indicate that analytical results from lenticular or biconvex obsidian surfaces are comparable to those from flat surfaces and pressed powder pellets, paving the way for the nondestructive analysis characterization of glass artifacts (Hughes 1986:35–37; Jack 1976). The minimum optimal sample size for analysis has been found to be approximately 10 mm in diameter and 1.5–2.0 mm thick. Later experimental studies conducted by Shackley and Hampel (1993) using samples with flat and slightly irregular surface geometries have corroborated Hughes' initial observations. In a similar experiment, Jackson and Hampel (1993) determined that for accurate results the minimum size of an artifact should be about 10 mm in diameter and 1.5 mm thick. Details about the effects of sample size and surface geometry are discussed in detail by Davis et al. (1998). Agreement between the U. S. Geological Survey standard RGM-1 (Glass Mountain obsidian) values and obsidian test samples was good at 1 mm thickness and improved markedly to a thickness of 3 mm.

Correlation of Artifacts and Geologic Sources. The diagnostic trace element values used to characterize the samples are compared directly to those for known obsidian sources such as those reported in the literature (Skinner 1998) and with unpublished trace element data collected through analysis of geologic source samples. Artifacts are correlated to a parent obsidian source or chemical source group if diagnostic trace element values fall within about two standard deviations of the analytical uncertainty of the known upper and lower limits of chemical variability recorded for the source. Occasionally, visual attributes are used to corroborate the source assignments although sources are never assigned on the basis of only megascopic characteristics.

Diagnostic trace elements, as the term is used here, refer to trace element abundances that show low intrasource variation and uncertainty along with distinguishable intersource variability. In addition, this refers to elements measured by X-ray fluorescence analysis with high precision and low analytical uncertainty. In short, diagnostic elements are those that allow the clearest geochemical distinction between sources. Trace elements generally refer to those elements that occur in abundances of less than about 1000 ppm in a sample. For simplicity in this report, we use the term synonymously with major and minor elements such as iron, titanium, and manganese, which may be present in somewhat larger quantities.

Obsidian Hydration Analysis

Introduction. The obsidian hydration dating method was introduced to the archaeological community in 1960 by Irving Friedman and Robert Smith of the U. S. Geological Survey (Friedman and Smith 1960). The potential of the method in archaeological chronologic studies was quickly recognized and research concerning the effect of different variables on the rate of hydration has continued to the present day by Friedman and others.

When a new surface of obsidian is exposed to the atmosphere, such as during the manufacture of glass tools, water begins to slowly diffuse from the surface into the interior of the specimen. When this hydrated layer or rind reaches a thickness of about 0.5 μm, it becomes recognizable as a birefringent rim when observed as a thin section under a microscope. Hydration rims formed on artifacts can vary in width from less than one micron for items from the early historic period to nearly 30 μm for early sites in Africa (Michels et al. 1983a; Origer 1989).

Formation of the hydration rim is affected not only by time but also by several other variables. The most important of these are chemical composition and temperature, although water vapor pressure and soil alkalinity may also play a role in some contexts. The effects of these variables have often been summarized and will not be discussed further here (Freter 1993; Friedman and Obradovich 1981; Friedman et al. 1994; Michels and Tsong 1980; Stevenson et al., 1993, 1998; see Skinner and Tremaine 1993 for additional references).

Once a hydration layer has been measured, it can be used to determine the relative ages of items or, in some circumstances, can be converted into an *estimated* absolute age. In order to transform the hydration rim value to a calendar age, the rate of the diffusion of water into the glass must be determined or estimated. The hydration rate is typically established empirically through the calibration of measured samples recovered in association with materials whose cultural age is known or whose age can be radiometrically determined, usually through radiocarbon dating methods (Meighan 1976). The hydration rate can also be determined experimentally, an approach that has shown increasing promise in recent years (Friedman and Trembour 1983; Michels et al. 1983a, 1983b; Tremaine 1989, 1993).

Sample Preparation Methods. An appropriate section of each artifact is selected for hydration slide preparation. The location of the section is determined by the morphology and the perceived potential of the location to yield information on the manufacture, use, and discard of the artifact. Two parallel cuts are made into the edge of the artifact using a lapidary saw equipped with 4-inch diameter diamond-impregnated .004" thick blades. These cuts produce a cross-section of the artifact approximately one millimeter thick which is removed from the artifact and mounted on a petrographic microscope slide with Lakeside thermoplastic cement. The mounted specimen slide is ground in a slurry of 600 grade optical-quality corundum abrasive on a plate glass lap. This initial grinding of the specimen reduces its thickness by approximately one half and removes any nicks from the edge of the specimen produced during cutting. The specimen is then inverted and ground to a final thickness of 30-50 microns, removing nicks from the other side of the specimen. The result is a thin cross-section of the surfaces of the artifact.

The prepared slide is measured using an Olympus BHT petrographic microscope fitted with a filar screw micrometer eyepiece. A Panasonic color CCTV camera is mounted on the filar eyepiece and the image is directed to a Panasonic color video monitor. The filar eyepiece is used to measure the thickness of the

hydration band projected onto the high resolution monitor. The specimen is first scanned under crossed polarizers and a first-order red (gypsum) plate in order to identify the birefringent hydration layer; the hydration layer is scanned under a magnification of 500X, 750X, or 1250X. The magnification is generally selected with regard to the opacity of the obsidian and the width of the hydration layer. When a clearly defined hydration layer is identified, the section is centered in the field of view to minimize parallax effects. Four rim measurements are typically recorded for each artifact or examined surface. Narrow rinds (under approximately two microns) are usually examined under a higher magnification. Hydration rinds smaller than one micron often cannot be resolved by optical microscopy.

Hydration thicknesses are reported to the nearest 0.1 μm and represent the mean value for all readings. Standard deviation values for each measured surface indicate the variability for hydration thickness measurements recorded for each specimen. It is important to note that these values reflect only the reading uncertainty of the rim values and do not take into account the resolution limitations of the microscope or other sources of uncertainty that enter into the formation of hydration rims (Meighan 1981, 1983). Any attempts to convert rind measurements to absolute dates should be approached with great care and considerable skepticism, particularly when rates are borrowed from existing literature sources. When considered through long periods, the variables affecting the development of hydration rims are complex, and there is no assurance that artifacts recovered from similar provenances or locales have shared thermal and cultural histories.

Results of Analysis

X-Ray Fluorescence Analysis

Four geochemical source groups, all of which were correlated with known geologic sources, were identified among the 25 artifacts that were characterized by X-ray fluorescence analysis. The locations of the site and the identified obsidian sources are shown in Figure 1 and Figure 3. Analytical results are presented in Table A-1 in the Appendix and are summarized in Table 1 and Figure 2. Descriptive information about all identified obsidian sources is outlined in Table 2.

Table 1. Geologic sources of obsidian identified by trace element analysis of artifacts.

Obsidian Source	N =	Percentage
Bodie Hills	2	8.0
Casa Diablo (Lookout Mountain)	2	8.0
Mt. Hicks	20	80.0
Silverpeak	1	4.0
Total	**25**	**100.0**

Figure 1. Locations of archaeological site and identified obsidian sources.

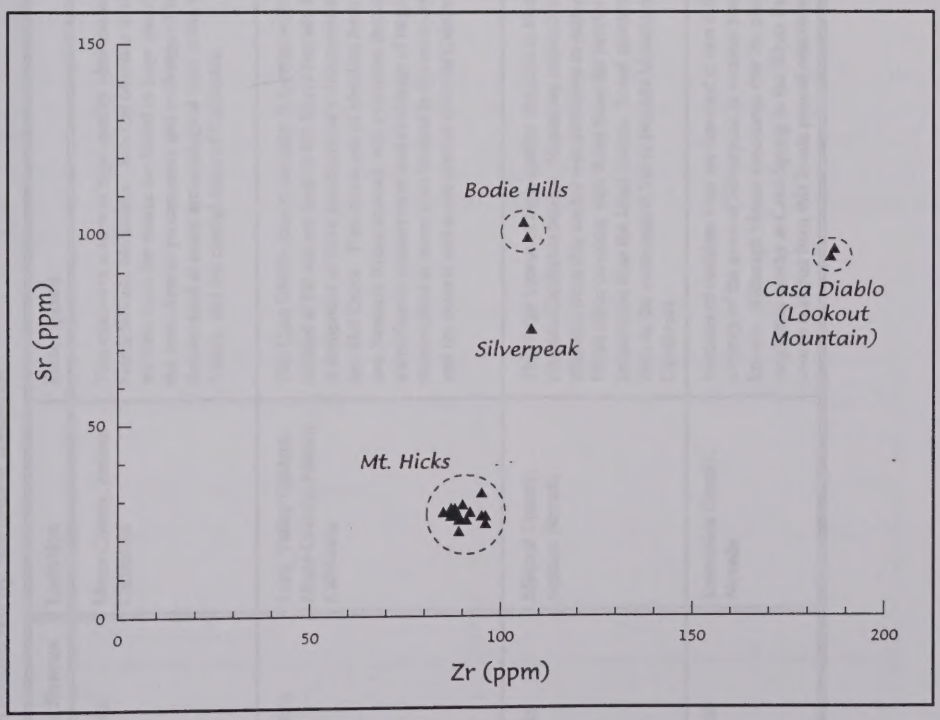

Figure 2. Scatterplot of strontium (Sr) plotted versus zirconium (Zr) for analyzed artifacts.

Table 2. Descriptions of obsidian sources identified in the current investigation. Summaries include results of unpublished field and geochemical source research conducted by Northwest Research.

Geologic Source	Location	Description	References
Bodie Hills	Mono County, eastern California	This extensive source of high-quality obsidian is located north of Mono Lake on the eastern side of the Sierra Nevada Mountains. Worked obsidian is reported to cover a total area of at least 8 km^2 and artifacts from the source are found in large quantities throughout east-central California. Evidence of the trans-Sierran procurement and exchange of large quantities of glass from Bodie Hills is well-documented at many archaeological sites in the west-central Sierra Nevada Mountains, the Central Valley, and the central coast of California.	Basgall 1989 Ericson 1981, 1982 Ericson et al. 1976 Goldberg et al. 1990 Jackson 1984 Jackson and Ericson 1994 Singer and Ericson 1977
Casa Diablo	Long Valley Caldera, Mono County, eastern California	The Casa Diablo source complex is located within Long Valley Caldera, a large volcanic depression located at the eastern base of the Sierra Nevada Mountains in eastern California. The source complex is composed of three geochemically distinguishable subgroups – Lookout Mountain, Sawmill Ridge, and Hot Creek. Prehistoric use of obsidian from Casa Diablo, primarily from the Lookout Mountain and Sawmill Ridge sources, was extensive throughout eastern and central California. Evidence of trans-Sierran procurement and exchange of large quantities of glass from the source area is well-documented at many sites located in the west-central Sierra Nevada Mountains, the Central Valley, and the central and south-central coast of California.	Bailey 1989 Bailey et al. 1976 Basgall 1989 Bouey and Basgall 1984 Ericson 1981, 1982 Ericson et al. 1976 Goldberg et al. 1990 Hughes 1994 Jackson 1984 Jackson and Ericson 1994
Mt. Hicks	Mineral County, western Nevada	This large source of high-quality obsidian is located in western Nevada about 10 km east of the Nevada-California border. Numerous prehistoric quarry sites are located at Mt. Hicks and use of obsidian from this source was extensive in east-central California. Characterized artifacts from Mt. Hicks often co-occur with those from the nearby Bodie Hills source, although usually in smaller proportions than the latter source. Small quantities of Mt. Hicks obsidian are also found at numerous sites in the west-central Sierra Nevada Mountains, the Central Valley, and the central coast of California.	Basgall 1989 Ericson et al. 1976 Goldberg et al. 1990
Silverpeak	Esmeralda County, Nevada	Nodules of obsidian float are reported at two different locations (one of them mine tailings) in the vicinity of the town of Silverpeak in western Nevada. The primary location of this source is not yet known. Although Moore speculates that the obsidian float assigned to the Silverpeak source originates nearby at Cave Spring in the Silver Peak Mountains, subsequent trace element analysis of source material from this locale proved otherwise. Prehistoric use of the source is very poorly known.	Moore 1997 Thomas 1983

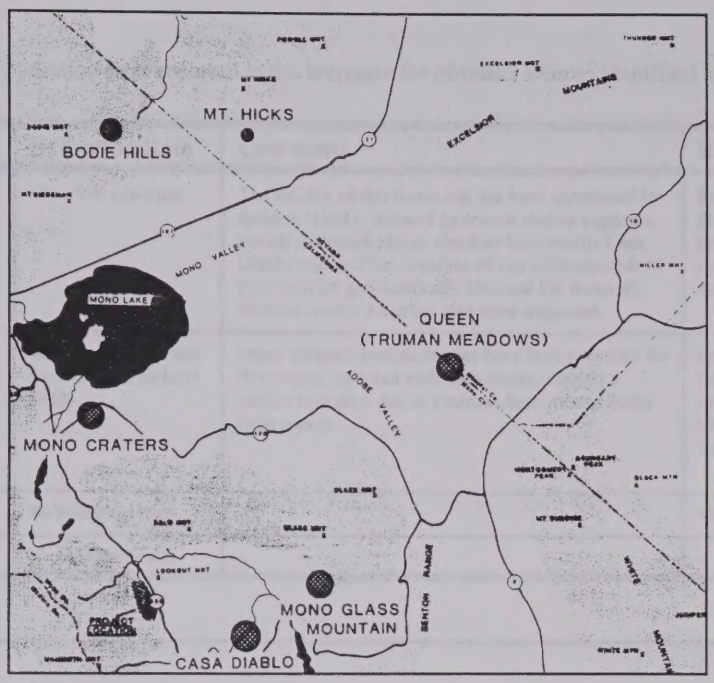

Figure 3. Distribution of major east-central California obsidian sources (adapted from Goldberg et al. 1990:19).

Obsidian Hydration Analysis

The 25 samples characterized by X-ray fluorescence analysis and an additional 20 artifacts were prepared for obsidian hydration rim measurements. The analysis yielded 49 measurable rims. The specimens are curated at the Northwest Research Obsidian Studies Laboratory under accession number 98-73. The results of the analysis are summarized in Table 3 and Figure 4 and are reported in Table B-1 in the Appendix. Information regarding obsidian hydration rate research for the identified obsidian sources is summarized in Table 4.

Table 3. Summary of results of obsidian hydration rim measurements. Totals include all successfully measured rims.

Obsidian Source	N =	Range (microns)
Bodie Hills	4	3.5 - 9.0
Casa Diablo (Lookout Mountain)	2	6.1 - 6.9
Mt. Hicks	22	3.2 - 12.2, 54.2 [A]
Silverpeak	1	5.7
No Source Determined	20	3.5 - 3.9
Total	49	–

[A] 54.2 µm value is associated with cortex.

Table 4. Different hydration rates reported in the literature for obsidian sources identified in the current investigation.

Geologic Source	Hydration Rate	Comments	Reference
Bodie Hills	650 - 670 years/μm	The validity of this linear rate has been questioned by Jackson (1984). Induced hydration studies suggest a similar hydration rate as obsidian from nearby Casa Diablo source. The existence of two different rates of hydration for geochemically identical but texturally different source areas has also been suggested.	Bieling 1992 Singer and Ericson 1977 Ericson 1981, 1982 Fredrickson 1991 Jackson 1984
Casa Diablo	Several reported rates (see Hall and Jackson 1989)	Many different hydration rates have been proposed for this source. Induced hydration studies suggest a similar hydration rate as obsidian from nearby Bodie Hills source.	Ericson 1981, 1982 Hall and Jackson 1989 Jackson 1984 Meighan 1983 Tremaine and Fredrickson 1988
Mt. Hicks	No published rates	–	Meighan 1983
Silverpeak	No published rates	–	–

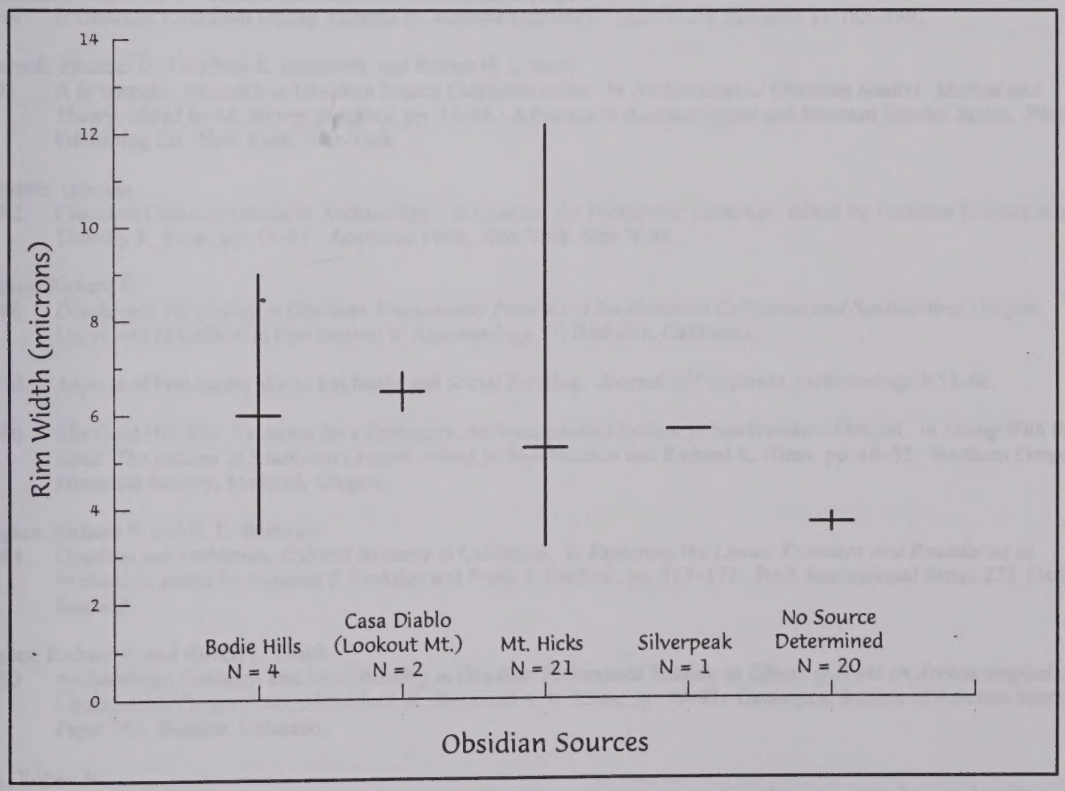

Figure 4. Range of obsidian hydration measurements for artifacts with successfully measured rims. The vertical bar spans the maximum to minimum values; the horizontal tic is placed at the mean value. Range of Mt. Hicks values does not include cortex rim measurement of 54.2 microns.

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Appendix

Results of X-Ray Fluorescence and Obsidian Hydration Analysis

Northwest Research Obsidian Studies Laboratory

Table A-1. Results of XRF Studies: Trench Canyon Site (CA-017-97-29), Mono County, California

Site	Specimen No.	Catalog No.	Trace Element Concentrations											Ratios		Artifact Source/Chemical Type
			Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	
CA-017-97-29	1	97-29-S1-A1	52	33	157	94	20	186	14	866	259	NM	1.29	52.9	48.3	Casa Diablo (Lookout Mountain)
			± 7	3	3	7	3	7	2	97	47	NM	0.11			
CA-017-97-29	2	97-29-S1-A2	46	37	209	75	10	108	18	778	415	122	0.75	18.8	32.8	Silverpeak
			± 7	3	3	7	3	7	2	96	47	12	0.11			
CA-017-97-29	3	97-29-S3-F1	38	30	167	27	13	88	21	544	349	NM	0.52	16.7	33.8	Mt. Hicks
			± 6	3	3	7	3	7	1	95	47	NM	0.11			
CA-017-97-29	4	97-29-S3-F2	36	36	152	27	16	85	20	352	256	NM	0.36	17.7	37.7	Mt. Hicks
			± 7	3	3	7	3	7	2	95	47	NM	0.11			
CA-017-97-29	5	97-29-S3-F3	26	36	157	26	13	87	19	470	302	NM	0.42	16.6	32.7	Mt. Hicks
			± 7	3	3	7	3	7	2	95	47	NM	0.11			
CA-017-97-29	6	97-29-S3-F4	36	38	162	26	15	88	21	657	389	NM	0.67	18.3	35.1	Mt. Hicks
			± 6	2	3	7	3	7	1	95	47	NM	0.11			
CA-017-97-29	7	97-29-S3-F5	38	42	189	26	18	87	27	591	384	NM	0.52	14.8	31.0	Mt. Hicks
			± 6	2	3	7	3	7	1	95	47	NM	0.11			
CA-017-97-29	8	97-29-S3-F6	37	33	154	24	13	96	19	578	205	NM	0.26	18.0	18.2	Mt. Hicks
			± 7	3	4	7	3	7	2	95	47	NM	0.11			
CA-017-97-29	9	97-29-S3-F7	29	41	179	99	13	107	14	388	270	NM	0.36	16.6	34.5	Bodie Hills
			± 7	3	4	7	3	7	2	95	47	NM	0.11			
CA-017-97-29	10	97-29-S3-F8	35	36	166	28	15	88	24	536	362	NM	0.55	16.6	35.7	Mt. Hicks
			± 6	3	3	7	3	7	1	95	47	NM	0.11			
CA-017-97-29	11	97-29-S3-F9	34	39	171	29	12	90	20	507	290	NM	0.42	17.3	30.3	Mt. Hicks
			± 7	3	3	7	3	7	2	95	47	NM	0.11			
CA-017-97-29	12	97-29-S3-F10	38	36	159	22	16	89	19	687	352	NM	0.65	19.8	32.5	Mt. Hicks
			± 6	2	3	7	3	7	1	95	47	NM	0.11			
CA-017-97-29	33	97-29-S4-A1	41	48	197	103	15	106	19	468	242	NM	0.31	16.8	25.6	Bodie Hills
			± 7	3	4	7	3	7	2	95	47	NM	0.11			
CA-017-97-29	34	97-29-S4-A2	40	34	158	96	17	187	12	873	246	NM	1.18	51.9	44.1	Casa Diablo (Lookout Mountain)
			± 6	2	3	7	3	7	2	96	47	NM	0.11			
CA-017-97-29	35	97-29-S4-A3	40	40	168	32	15	95	27	522	331	NM	0.49	16.7	33.2	Mt. Hicks
			± 6	3	3	7	3	7	2	95	47	NM	0.11			
CA-017-97-29	36	97-29-S5-F1	28	34	167	25	15	89	22	530	287	NM	0.48	19.4	32.2	Mt. Hicks
			± 7	3	3	7	3	7	2	95	47	NM	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Table A-1. Results of XRF Studies: Trench Canyon Site (CA-017-97-29), Mono County, California

Site	Specimen No.	Catalog No.		Trace Element Concentrations											Ratios		Artifact Source/Chemical Type
				Zn	Pb	Rb	Sr	Y	Zr	Nb	Ti	Mn	Ba	$Fe_2O_3^T$	Fe:Mn	Fe:Ti	
CA-017-97-29	37	97-29-S5-F2		39	36	153	27	11	87	19	493	311	NM	0.48	17.5	34.3	Mt. Hicks
			±	7	3	3	7	3	7	2	95	47	NM	0.11			
CA-017-97-29	38	97-29-S5-F3		37	42	176	27	13	92	24	621	368	NM	0.65	18.8	35.7	Mt. Hicks
			±	6	3	3	7	3	7	2	95	47	NM	0.11			
CA-017-97-29	39	97-29-S5-F4		34	36	154	25	13	91	20	382	290	NM	0.40	16.6	38.1	Mt. Hicks
			±	6	3	3	7	3	7	2	95	47	NM	0.11			
CA-017-97-29	40	97-29-S5-F5		24	37	163	27	14	88	23	602	358	NM	0.53	16.4	31.2	Mt. Hicks
			±	7	2	3	7	3	7	1	95	47	NM	0.11			
CA-017-97-29	41	97-29-S5-F6		34	43	174	26	16	95	23	448	266	NM	0.36	16.7	29.8	Mt. Hicks
			±	7	3	4	7	3	7	2	95	47	NM	0.11			
CA-017-97-29	42	97-29-S5-F7		29	43	160	26	14	89	22	618	373	NM	0.61	17.6	34.2	Mt. Hicks
			±	6	2	3	7	3	7	1	95	47	NM	0.11			
CA-017-97-29	43	97-29-S5-F8		34	35	157	28	15	87	22	500	361	NM	0.54	16.4	37.6	Mt. Hicks
			±	6	2	3	7	3	7	1	95	47	NM	0.11			
CA-017-97-29	44	97-29-S5-F9		33	38	176	29	15	90	22	552	357	NM	0.56	17.2	35.3	Mt. Hicks
			±	6	2	3	7	3	7	2	95	47	NM	0.11			
CA-017-97-29	45	97-29-S5-F10		40	40	163	26	17	96	19	508	356	NM	0.53	16.5	36.6	Mt. Hicks
			±	6	2	3	7	3	7	1	95	47	NM	0.11			
NA	RGM-1	RGM-1		37	18	150	104	26	217	10	1630	271	783	1.89	72.1	37.2	RGM-1 Reference Standard
			±	6	2	3	7	3	7	1	97	47	13	0.11			

All trace element values reported in parts per million; ± = analytical uncertainty estimate (in ppm). Iron content reported as weight percent oxide.
NA = Not available; ND = Not detected; NM = Not measured.; * = Small sample.

Northwest Research Obsidian Studies Laboratory

Table B-1. Obsidian Hydration Results and Sample Provenience: Trench Canyon Site (CA-017-97-29), Mono County, California

Site	Specimen No.	Catalog No.	Unit	Depth	Artifact Type [A]	Artifact Source	Hydration Rims		Comments [B]
							Rim 1	Rim 2	
CA-017-97-29	1	97-29-S1-A1	--	Surface	PPT	Casa Diablo (Lookout Mt)	6.1 ± 0.1	NM ± NM	Same rim on BRE
CA-017-97-29	2	97-29-S1-A2	--	Surface	PPT	Silverpeak	5.7 ± 0.1	NM ± NM	--
CA-017-97-29	3	97-29-S3-F1	Loci 1	Surface	DEB	Mt. Hicks	3.2 ± 0.1	NM ± NM	--
CA-017-97-29	4	97-29-S3-F2	Loci 1	Surface	DEB	Mt. Hicks	4.2 ± 0.0	12.2 ± 1.6	Larger rim is cortex; HV
CA-017-97-29	5	97-29-S3-F3	Loci 1	Surface	DEB	Mt. Hicks	3.6 ± 0.1	NM ± NM	--
CA-017-97-29	6	97-29-S3-F4	Loci 1	Surface	DEB	Mt. Hicks	3.9 ± 0.1	NM ± NM	--
CA-017-97-29	7	97-29-S3-F5	Loci 1	Surface	DEB	Mt. Hicks	3.8 ± 0.1	NM ± NM	--
CA-017-97-29	8	97-29-S3-F6	Loci 1	Surface	DEB	Mt. Hicks	3.6 ± 0.1	NM ± NM	--
CA-017-97-29	9	97-29-S3-F7	Loci 1	Surface	DEB	Bodie Hills	7.1 ± 0.1	9.0 ± 0.0	--
CA-017-97-29	10	97-29-S3-F8	Loci 1	Surface	DEB	Mt. Hicks	3.3 ± 0.1	NM ± NM	--
CA-017-97-29	11	97-29-S3-F9	Loci 1	Surface	DEB	Mt. Hicks	4.0 ± 0.1	NM ± NM	--
CA-017-97-29	12	97-29-S3-F10	Loci 1	Surface	DEB	Mt. Hicks	3.7 ± 0.1	NM ± NM	--
CA-017-97-29	13	97-29-S3-F11	Loci 1	Surface	DEB	No source determined	3.7 ± 0.1	NM ± NM	--
CA-017-97-29	14	97-29-S3-F12	Loci 1	Surface	DEB	No source determined	3.7 ± 0.1	NM ± NM	--
CA-017-97-29	15	97-29-S3-F13	Loci 1	Surface	DEB	No source determined	3.9 ± 0.1	NM ± NM	--
CA-017-97-29	16	97-29-S3-F14	Loci 1	Surface	DEB	No source determined	3.7 ± 0.1	NM ± NM	--
CA-017-97-29	17	97-29-S3-F15	Loci 1	Surface	DEB	No source determined	3.8 ± 0.1	NM ± NM	--
CA-017-97-29	18	97-29-S3-F16	Loci 1	Surface	DEB	No source determined	3.7 ± 0.1	NM ± NM	--
CA-017-97-29	19	97-29-S3-F17	Loci 1	Surface	DEB	No source determined	3.9 ± 0.1	NM ± NM	--
CA-017-97-29	20	97-29-S3-F18	Loci 1	Surface	DEB	No source determined	3.5 ± 0.1	NM ± NM	--
CA-017-97-29	21	97-29-S3-F19	Loci 1	Surface	DEB	No source determined	3.5 ± 0.1	NM ± NM	--
CA-017-97-29	22	97-29-S3-F20	Loci 1	Surface	DEB	No source determined	3.9 ± 0.1	NM ± NM	--
CA-017-97-29	23	97-29-S3-F21	Loci 1	Surface	DEB	No source determined	3.7 ± 0.1	NM ± NM	--
CA-017-97-29	24	97-29-S3-F22	Loci 1	Surface	DEB	No source determined	3.7 ± 0.1	NM ± NM	--
CA-017-97-29	25	97-29-S3-F23	Loci 1	Surface	DEB	No source determined	3.5 ± 0.1	NM ± NM	--

[A] BIF = Biface; DEB = Debitage; PPT = Projectile Point
[B] See text for explanation of comment abbreviations
NA = Not Available; NM = Not Measured; * = Small sample

Northwest Research Obsidian Studies Laboratory

Table B-1. Obsidian Hydration Results and Sample Provenience: Trench Canyon Site (CA-017-97-29), Mono County, California

Site	Specimen No.	Catalog No.	Unit	Depth	Artifact Type [A]	Artifact Source	Hydration Rims		Comments [B]
							Rim 1	Rim 2	
CA-017-97-29	26	97-29-S3-F24	Loci 1	Surface	DEB	No source determined	3.7 ± 0.1	NM ± NM	--
CA-017-97-29	27	97-29-S3-F25	Loci 1	Surface	DEB	No source determined	3.7 ± 0.1	NM ± NM	--
CA-017-97-29	28	97-29-S3-F26	Loci 1	Surface	DEB	No source determined	3.7 ± 0.1	NM ± NM	--
CA-017-97-29	29	97-29-S3-F27	Loci 1	Surface	DEB	No source determined	3.7 ± 0.1	NM ± NM	--
CA-017-97-29	30	97-29-S3-F28	Loci 1	Surface	DEB	No source determined	3.7 ± 0.1	NM ± NM	--
CA-017-97-29	31	97-29-S3-F29	Loci 1	Surface	DEB	No source determined	3.5 ± 0.1	NM ± NM	--
CA-017-97-29	32	97-29-S3-F30	Loci 1	Surface	DEB	No source determined	3.7 ± 0.1	NM ± NM	--
CA-017-97-29	33	97-29-S4-A1	--	Surface	PPT	Bodie Hills	4.4 ± 0.1	3.5 ± 0.1	Larger rim on ventral surface
CA-017-97-29	34	97-29-S4-A2	--	Surface	BIF	Casa Diablo (Lookout Mt)	6.9 ± 0.1	NM ± NM	Same rim on BRE
CA-017-97-29	35	97-29-S4-A3	--	Surface	PPT	Mt. Hicks	7.7 ± 0.1	NM ± NM	Same rim on BRE
CA-017-97-29	36	97-29-S5-F1	Loci 1	Surface	DEB	Mt. Hicks	3.3 ± 0.1	NM ± NM	--
CA-017-97-29	37	97-29-S5-F2	Loci 1	Surface	DEB	Mt. Hicks	3.6 ± 0.0	NM ± NM	--
CA-017-97-29	38	97-29-S5-F3	Loci 1	Surface	DEB	Mt. Hicks	3.3 ± 0.1	NM ± NM	--
CA-017-97-29	39	97-29-S5-F4	Loci 1	Surface	DEB	Mt. Hicks	3.3 ± 0.1	NM ± NM	--
CA-017-97-29	40	97-29-S5-F5	Loci 1	Surface	DEB	Mt. Hicks	3.3 ± 0.1	NM ± NM	--
CA-017-97-29	41	97-29-S5-F6	Loci 2	Surface	DEB	Mt. Hicks	10.2 ± 0.1	NM ± NM	--
CA-017-97-29	42	97-29-S5-F7	Loci 2	Surface	DEB	Mt. Hicks	7.2 ± 0.0	NM ± NM	--
CA-017-97-29	43	97-29-S5-F8	Loci 2	Surface	DEB	Mt. Hicks	6.6 ± 0.1	NM ± NM	--
CA-017-97-29	44	97-29-S5-F9	Loci 2	Surface	DEB	Mt. Hicks	9.0 ± 0.0	NM ± NM	--
CA-017-97-29	45	97-29-S5-F10	Loci 2	Surface	DEB	Mt. Hicks	8.2 ± 0.1	54.2 ± 0.0	Larger rim = dorsal cortex

[A] BIF = Biface; DEB = Debitage; PPT = Projectile Point
[B] See text for explanation of comment abbreviations
NA = Not Available; NM = Not Measured; * = Small sample

Abbreviations and Definitions Used in the Comments Column

1SO - (1 Surface Only). Hydration was observed on only one surface or side of the thin section.

A, B, C - 1st, 2nd, and 3rd cuts, respectively.

BEV - (Beveled). Artifact morphology or cut configuration resulted in a beveled thin section edge.

BRE - (BREak). The thin section cut was made across a broken edge of the artifact.The resulting hydration measurements may provide approximate chronological information about the age of the break relative to its time of manufacture.

DES - (DEStroyed). The artifact or flake was destroyed in the process of thin section preparation. This sometimes occurs during the preparation of extremely small items, such as pressure flakes.

DFV - (Diffusion Front Vague). The diffusion front, or the visual boundary between hydrated and unhydrated portions of the specimen, are poorly defined.This can result in less precise measurements than can be obtained from sharply demarcated diffusion fronts.The technician must estimate the hydration boundary when a vague diffusion front appears as a relatively thick, dark line or a gradation in color or brightness between hydrated and unhydrated layers.

DIS - (DIScontinuous). A discontinuous or interrupted hydration rind was observed on the thin section.

HV - (Highly Variable). The hydration rind exhibits variable thickness along continuous surfaces.This variability can occur with very well-defined bands as well as those with irregular or vague diffusion fronts.

IRR - (IRRegular). The surfaces of the thin section (the outer surfaces of the artifact) are uneven and measurement is difficult.

NOT - (NOT obsidian). Petrographic characteristics of the artifact or obsidian specimen indicate that the specimen is not obsidian.

NVH - (No Visible Hydration). No hydration rind was observed on one or more surfaces of the specimen. This does not mean that hydration is absent, only that hydration was not observed.Hydration rinds smaller than one micron often are not birefringent and are difficult to see and accurately measure using optical microscopy.

OPA - (OPAque). The specimen is too opaque for measurement and cannot be further reduced in thickness.

PAT - (PATinated). This description is usually noted when there is a problem in measuring the thickness of the hydration rind, and refers to the unmagnified surface characteristics of the artifact, possibly indicating the source of the measurement problem.Only extreme patination is normally noted.

REC - (RECut). More than one thin section was prepared from an archaeological specimen. Multiple thin sections are made if preparation quality on the initial specimen is suspect or obviously poor.

UNR - (UNReadable). The optical quality of the hydration rind is so poor that accurate measurement is not possible.Poor thin section preparation is not a cause.

WEA - (WEAthered). The artifact surface appears to be damaged by wind erosion or other mechanical action.

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